AMC'S FUTURE STRATEGIC AIRLIFTER:

THE BLENDED WING BODY?

GRADUATE RESEARCH PROJECT

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AFIT/IMO/ENS/10-01

DEPARTMENT OF THE AIR FORCE

AIR UNIVERSITY

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Abstract

What is the future design of Air Mobility Command (AMC) aircraft? One possible answer is a blended-wing-body design. The research problem examined in this report is to determine if a future Blended-Wing Body (BWB) aircraft will be more capable as compared to a more conventional design, the C-17. This research shows the capability of the BWB configuration using an AFIT-developed model called AMPCALC and a cost analysis based on those results.

There are two major issues when assessing a BWB aircraft: capability and fuel savings. This research tries to answer if a BWB aircraft, such as being designed by Boeing with NASA and the AF Research Labs, is more capable than a C-17 and what are the potential fuel savings for operating a BWB aircraft over the C-17. This is an early look into the BWB configuration and its merits for consideration as a potential strategic airlifter. The BWB design must now be evaluated to be considered as a future replacement for current AMC airlift aircraft. This research gives decision makers an idea of the possible benefits of this revolutionary concept.

Acknowledgments

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Table of Contents

Page

List of Tables and Graphs

List of Figures

I. Introduction

Since the early 20th century airplane design has been primarily based on a conventional tube and wing design. With better technology and more constraints on fossil fuels and capital, it is time to research new designs that break away from the long-standing paradigm. One design that shows much promise is the Blended-Wing Body (BWB) design currently being developed by Boeing, National Aeronautics and Space Administration (NASA), and the Air Force (AF) Research Labs. The idea has been around since the 1930s, but now shows stronger progress based on new technologies. In the 1980s NASA posed the challenge of producing a highly fuel efficient aircraft to the aerospace industry. They wanted engineers and researchers to start with a clean slate disregarding conventionally designed aircraft. McDonnell Douglas took the initial lead in developing the BWB and then Boeing took over when they acquired McDonnell Douglas' expertise.

Problem Statement

What is the capability and economic feasibility of a BWB type strategic airlifter? More precisely will a BWB designed airlifter be cheaper than a current C-17 Globemaster. Can a BWB design produce more ton-miles than a C-17? Even if a BWB designed aircraft is more efficient than a conventionally designed aircraft, what else must change in order to utilize this newly designed airlifter? The problem is to see if the BWB design is a contender for the C-X, the replacement for C-5 and C-17. The AF sees the C-X as a strong possibility based on the Air Mobility Master Plan 2010 (AMMP). "Several assessments indicate there is a requirement to replace our strategic airlift fleet in the 2040 time frame" (U.S. Air Force, HQ AMC/A8XPL, 2009, p. 32). It took 14 years to bring the C-17 from initial concept to operational capability. This means the AF must start very early to replace all weapon systems. Another factor that

makes the BWB such an important concept is the reduction of fuel burn needed for this type of design. The AF is the largest consumer of fuel in the Department of Defense (DOD) and Air Mobility Command (AMC) is the largest consumer in the AF. It is imperative that AMC obtain the most fuel efficient weapon systems possible.

Research Questions

The research on the BWB design is focused on determining if it is more capable and more efficient as a future airlifter compared to a conventionally designed aircraft, like the C-17or C-5. One question that came out of this research is what is the right size for a BWB strategic airlifter. Overall, the research questions are derived from the problem statements above.

There is also the possibility of using a BWB aircraft as a future tanker. If proven capable, it would most likely compete for the KC-Z Request for Proposal (RFP). Another possible question deals with cost. Could the research and development by Boeing and NASA reduce the future costs of purchasing a BWB type C-X? These questions are not the primary focus of the research, but if answered would help future decision makers consider the viability of BWB design in the AF.

Research Hypothesis

My hypothesis is based on the reduction of weight for a BWB aircraft compared to a conventionally designed aircraft, such as the C-17 Globemaster. All the research that has been conducted has shown a 20-30% fuel savings for an aircraft of comparable size and capability. If the assumptions hold true for a BWB aircraft then the new aircraft should be more capable and economically feasible, due to fuel savings, than current airlifters, like the C-17. My hypothesis is that the BWB EET will be more capable and close sooner than the C-17. The BWB aircraft will also provide a significant cost savings over the C-17. This hypothesis is based, not only on

fuel savings, but some important assumptions. Firstly, in order for a new type of BWB aircraft to remain feasable it must be able to use current Material Handling Equipment (MHE). This includes current forklifts, Tonners and the 463 pallet system. It is important that current infrastructure be used, to include existing taxiways and runways. A BWB capability that requires military construction would negate the cost savings for a new BWB airlifter. Finally, not only does a BWB need to be more cost effective, it must be capable of carrying more cargo than current airlifters.

Research Focus

The research focus is to determine if a BWB aircraft is more capable as a replacement for the AF's current strategic airlifters, and can a BWB aircraft provide significant cost savings compared to a C-17.

Methodology

This research is a parametric study of the BWB aircraft based on quantitative data. A loading model, Air Mobility Planning Calculator (AMPCALC), is used to compare the loading and cargo capabilities of the BWB aircraft to the C-17 based on a simulated deployment of cargo from CONUS to the three overseas locations. Different distances, number of aircraft and load amounts are evaluated to see which aircraft is more capable in terms of closure time for the simulated deployment of cargo. The total tonnage for bulk cargo is used for each aircraft; oversized and outsized equipment was not evaluated in this research. The capability breakeven point is determined as compared to the C-17 for each different test run. The BWB aircraft's cargo capability is determined using AMC's requirements for the C-X and from Boeing's objectives for the X-48 program with their stated design specifications for the BWB EET. A cost analysis based on fuel burn for each aircraft is also conducted.

Limitations/Assumptions

There are limitations and assumptions in this research. An important assumption for any new airlifter is that current MHE can be used. This also includes current infrastructure at AMC bases. The size of the aircraft must remain within current limits for taxiways and runways. Also, the engines used for the BWB would have a comparable design specs to the most advanced engines used on the C-17. This allows a cost comparison between a C-17 and BWB type airlifter.

The loading configurations for the BWB airlifter are still very fluid. Multiple different interior designs could be used. One of the main concerns is how to pressurize a blended wing because it is not the typical tube design, which is easily pressurized for flight. The loading configuration has to work around this requirement. Multiple rows of pallets need to be used, as proposed by Boeing with their BWB Energy Efficient Transport (EET). These rows are lined up next to each other in the body similar to lining up multiple tubes. This could also help the pressurizing requirement. Research has already been conducted on the interior makeup of a BWB aircraft for an airline configuration. Figure 1 shows a possible interior for a future airline layout.

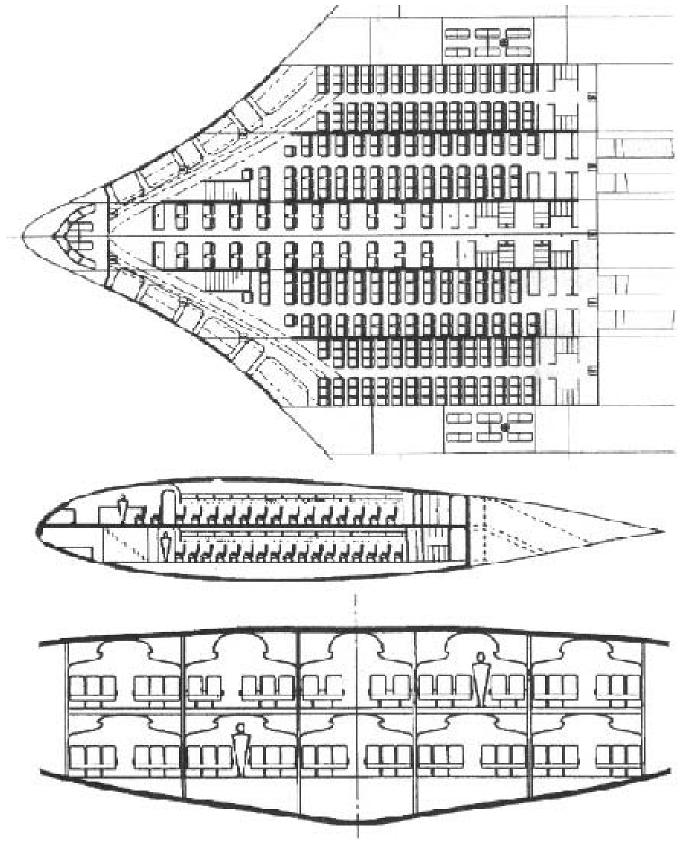


Figure 1. Blended Wing Body Internal Layout**,** (Scott, 2003)

As seen in figure 1, multiple tube type sections are used in order to accomplish interior pressurization. The interior configuration helps determine how the aircraft will be loaded and unloaded. Either front loading or rear loading is possible. A core assumption is that the BWB aircraft will carry oversized and outsized cargo.

The BWB airlifter is assumed to fly the same way a conventional aircraft flies. It is important that the aircrew not need any additional training, other than learning a new aircraft. With current technology and fly-by-wire systems this is possible. Because the BWB design does not utilize traditional horizontal and vertical stabilizers, an advanced fly-by-wire system is mandatory, similar to the B-2 and its flight control system.

Similar engine capabilities will also be used to compare the BWB and a conventional

airlifter. This helps make the capability comparison more uniform, although the BWB will have much more advanced engines. Also, the BWB design contributes to a better fuel burn based on the placement and utilization of a lesser number of engines.

The primary limitation to this research is that no BWB aircraft currently exists, except for test aircraft such as the X-48s. This makes it very difficult to conduct an accurate cost analysis based on its future capabilities.

Implications

If a BWB is economically feasible, the implications are far reaching not only for the military but also the civilian airline and cargo industry. Not only would fuel cost be reduced for an aircraft, whether military or civilian, but airlift in general would become more efficient. A BWB aircraft could carry more equipment, including oversized and outsized cargo, farther and cheaper than conventionally designed strategic airlifters. Besides the body design, newer engines that incorporate ultra-high bypass ratios are being tested to help give even more reductions in fuel burn. The goal is a 60% reduction in fuel burn.

Another important advantage that Boeing is studying, is noise reduction for the engines. A noise reduction with a BWB of 45% could be realized because the engines are situated on top of the airplane. A design characteristic that helps is that sound waves are bounced between the large winglets and deflected upwards. Not only does the noise reduction help reduce noise pollution, but it increases the stealth capability of the airlifter.

Another great attribute of a BWB designed aircraft is that it is very scalable. Depending on the load requirement, the aircraft can be sized to meet those needs. If the requirement drives the wing span to be too large for today ramps then folding wingtips can be used. Also, with a

slim profile, these aircraft have a lower radar cross section compared to conventional airlifters. Overall, a BWB designed airlifter would be more capable and reduce operations cost with less environmental impact.

II. Literature Review

There are many requirements to meet when developing a new weapon system. In the Air Force, all aircraft (including air mobility assets) must eventually be replaced. Since the C-5 was built in the 1970s and the C-17 production line is about to shut down, the next airlifter is now being considered. The next aircraft may be more tactical or strategic in nature based on future threats. Some of the factors that determine what the next airlifter will look like include economic considerations, mission requirements and technologies available. All these factors play an important part in the development of the next airlifter.

Economic Considerations

With the Defense budget shrinking, and many weapon systems being canceled as a result, it is now more difficult for the AF to acquire new aircraft. The AF plans to use the C-5 for at least 30 years and the C-17 for 30 more years (AMMP, 2008) for strategic lift. The C-130 Hercules, predominately used for tactical airlift, is planned for 40 years of use with the introduction of the C-130J. Even then, wing box replacements are planned for the C-130 until FY2048! Currently, the C-5 is primarily used for oversized and outsized cargo; transporting pallets is cheaper on commercial contract aircraft. The C-17 is used for both strategic and tactical airlift missions, to include direct delivery from the United States to the Area of Operation (AOR). An extreme example of the AF using their current weapon systems as long as possible is the B-52 Bomber and the KC-135 Tanker. The B-52 is programmed for 80+ years, with the KC-135 approaching 100 years of service. The AF is attempting to save money by utilizing weapon systems as long as possible by upgrading, versus replacing, aircraft. Many times, the costs of keeping an aging weapon system viable cuts into the cost savings of not procuring a new one.

The Department of Defense (DOD) budget is not growing due to the economy and the need to overhaul many government programs. Some of the programs that need overhauling include health care and the social security system. Hundreds of billions of dollars have already been spent on various recovery programs. The nation's debt has grown at an alarming rate to 1.4 trillion dollars just for 2009, according to the government (Dodaro, 2010). It will also take billions of dollars to pay for the health care plan. All of these demands, even if taxes are raised, have squeezed the government's budget and further forced the defense budget to slightly decrease over the next couple of years (Dodaro, 2010). The AF's budget could decrease more than other services due to current perception that the Air Force is not contributing as much to the current wars in Iraq and Afghanistan.

With the current budget constraints, and technologies costing more, the next airlifter, whether strategic, tactical or both, will need an efficient acquisition process. Along with acquisition process efficiency, the individual cost of each aircraft needs to be as low as possible. This cost goal can be achieved by economies of scale, buying more of the same aircraft to spread out the research and development costs. Utilizing more effective manufacturing techniques and cheaper materials like composites can help reduce costs. These requirements constraint the amount of technology, or capability, that can be designed into the next airlift platforms. The largest driving force of the design and structure of the next airlifters are the mission requirements.

Mission Requirements

Every two years the AMC releases the Air Mobility Master Plan (AMMP). The AMMP defines the future force requirements and force structure required to meet the national security needs of the country. Currently, the third priority under the AF's strategic plan is

“Recapitalizing and modernizing our aging aircraft, satellites and equipment… to optimize the military utility of our systems and to better meet 21st century challenges” (AMMP 2008, p.15). “First, we look at ‘airlift’ from a new perspective, as an overall capability where intertheater and intratheater missions merge into a single mission” (AMMP 2008, p.24). With the C-5 and C-17 planned for another 20-30 years of service, the AF is currently concentrating on replacing the tactical level aircraft, but will need to eventually replace the strategic mobility force.

The Air Force Concept of Operations (CONOPS) is the overall guidance that the Air Force uses through 2025. It falls under the AF’s strategic plan. “The CONOPS lays the foundation for our transformation to a capabilities-based Air and Space Expeditionary Force (AEF) through 2025” (AMMP 2008, p.15). By taking guidance from the DOD and AF, AMC frames the requirements that drive the size of the airlift force and what weapon systems are needed. The CONOPS helps set what future airlift assets should be. “Future Airlift assets must be capable of providing airlift support from point of embarkation to point of effect, delivering personnel and assets to any location on the globe including prepared, unprepared and austere airfields without the use of ground-based navigation aids and regardless of weather conditions” (AMMP 2008, p. 29).

There are two different paths that AMC is taking to develop the future mobility force. The first path, is to replace most C-130s, specifically C-130Es and C-130Hs, with the Joint Future Theater Lift (JFTL) aircraft. The second path is the C-X, which will replace the aging C-5s and C-17s, starting in the 2020 time frame. “Lastly, we will initiate procurement actions for the next Global Airlifter, the C-X, to replace C-5s and eventually C-17s. This aircraft will be optimized for the long range airlift of large amounts of bulk cargo, vehicles, and passengers” (AMMP 2008, p 32). Both the JFTL and C-X designs could use similar technologies to meet

future airlift requirements. Some technologies work well for different mission types but some are universal, such as defensive systems. Many technologies used to meet mission requirements are also scalable for different sizes of airplanes.

An important driver of mission requirements are customer needs, and the Army is the largest AMC customer. As the Army concentrates on the ability to move large portions of their forces quickly; this directly affects the type of airlifter needed to move those forces. The AF has already determined a problem with trying to move the Army's Stryker armored vehicles. Strykers were originally designed to fit into a C-130, or larger aircraft. Initial Strykers fit, but defensive improvements have made the Stryker too large for any C-130. "Additionally, the C-130J cargo compartment size is not large enough to carry the US Army's larger vehicles of the future combat systems now under development" (AMMP 2008, p. 8). This illustrates the importance of the next airlifter to match and meet the Army's requirements for their future combat weapon systems. The AF needs an airlifter that can handle large loads, but still land in a more austere location to meet their mission requirements and doctrine. "Within the US Army's dominant maneuver strategy, the MAF will not necessarily operate from aerial ports of debarkation and forward operating bases as we do today" (AMMP 2008, p.70). The Army not only requires an airlifter to move large equipment with roll-on and roll-off capability, but they need the equipment delivered anywhere on the battle field. This drives the design of the next airlifter, or airlifters, to meet tactical and/or strategic requirements.

Technologies Available

There are many current and developing technologies that will help determine the next airlifter's design. There are too many technologies to list, but two that could play an important part are lighter than air aircraft and BWB aircraft. "AMC has identified research, development,

test and evaluation (RDT&E) areas critical to its future success. Some of these areas include autonomous operations, defensive systems, energy conservation and efficiencies, human factors, austere area operations, all weather capability and vertical delivery" (AMMP 2008, p.8). These other technologies will be incorporated into any design that the Air Force chooses as inherent requirements to the airlift mission. "Interoperability and compatibility among our future systems will reduce engineering cost, lower operator and maintainer training costs, and increase effectiveness through improved velocity in operations" (AMMP 2008, p. 7).

Lighter Than Air Aircraft

Lighter than air aircraft, to include ultra large airships, show the ability to be able to move large amounts of cargo over most distances. "In January 2004, the Defense Advanced Research Projects Agency (DARPA) published a request for information in the Commerce Business Daily (CBD) for a "Heavy Lift Air Vehicle" capable of carrying "500 tons or more over intercontinental distances" (Gordon, 2005). Lockheed has shown the most interest and development progress among US defense contractors. By using a lighter than air aircraft, the lift-to-drag ratio becomes obsolete due to the buoyancy of the aircraft.   Since the aircraft use buoyancy to create lift, smaller engines can be used to propel the airship, reducing fuel burn and weight. Another advantage are the larger payloads that can be moved based on the size of the structure. Even hybrid type aircraft are being studied. The Army sees great advantage in these systems to support their multidimensional operations and operational maneuver.

The Army has demonstrated a strong interest in large airships and has even exercised small and large airships concepts in their Vigilant Warriors war games. One finding that the Army highlighted was a "crucial measure of successful force projection is not the speed with which the first combat element engages, but is rather the rate at which the United States and its

allies achieve decisive operational superiority" (Global Security ULA, 2009). Figure 2 shows a commercial hybrid airship.

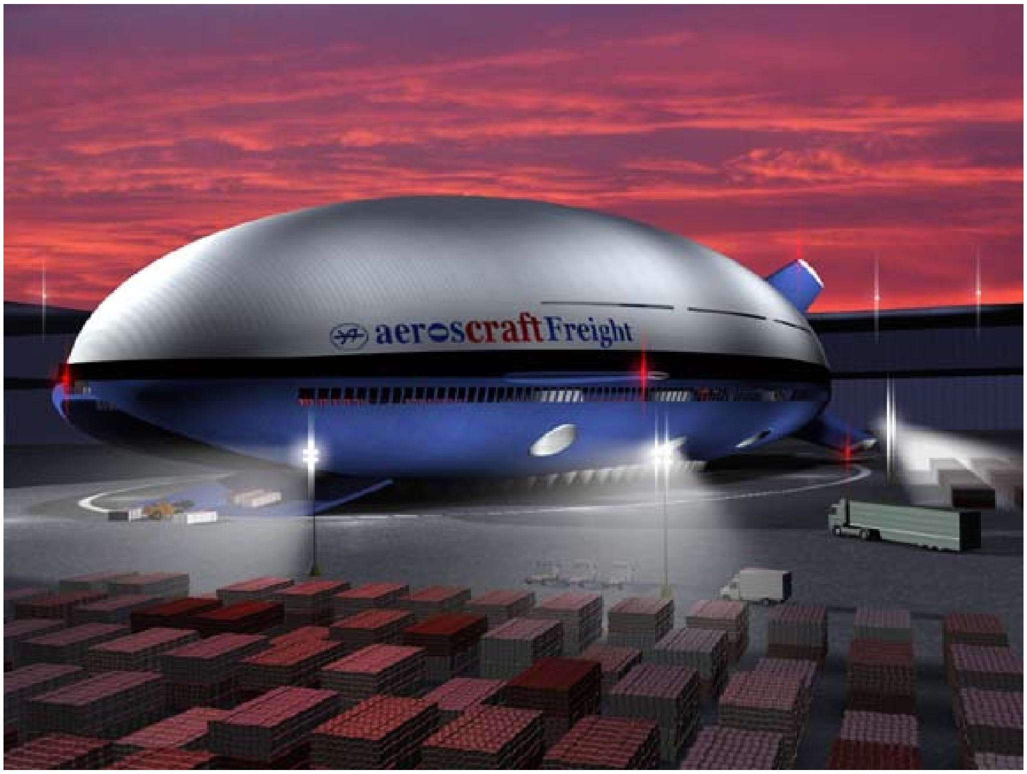


Figure 2. Future Hybrid Airship (Transportation and Logistics Blog, 2008)

One of the greatest limitations to an airship-based airlifter is the threat of surface to air missiles (SAM) or small-arms fire. Since these airships are larger, slower and less maneuverable than conventional aircraft, they are more susceptible to enemy fire. Depending on the mission, especially tactical operations, an airship would be able to face the risk. For strategic aircraft the threat is more manageable and makes an airship more viable. Another challenge to the lighter than air design is floor restrictions on heavy equipment, like armored vehicles. "Floor restrictions on the aircraft limited cargo to lighter items such as helicopters, light vehicles, and sustainment stocks" (Global Security ULA, 2009). If these limitations could be overcome, a hybrid airship could be used in conjunction with the next generation strategic airlifter because speed will always be a major requirement. This is why a BWB configuration may be more viable.

History of Blended Wing Body

After the Wright brothers first took flight, aircraft design quickly developed in the first part of the century. The primary design that ended up being developed was the traditional fuselage and wing design. This first design was developed with biplanes in the early 1910s. In the 1930s, both Germany and Canada tried a different approach with a BWB design type aircraft. This was a hybrid approach between a traditional type design and a flying wing similar to the B-2 bomber or the YB-49 of the 1950s. With a BWB design, the body of the aircraft is also a lifting body as are the wings. With a more traditional design, the fuselage does not produce lift, only the wings and horizontal stabilizers.

During the 1930s, an American aeronautical engineer named Vincent Burnelli developed a BWB design called the Burnelli CBY-3. The model below represents an accurate depiction of the aircraft and Figure 4 shows the CBY-3 inflight. The aircraft was actually built in Canada and used in the Canadian Car and Foundry for its ability to fly over wilderness and takeoff and land within 640 ft. The CBY-3 was an all metal aircraft similar to the DC-3 but could carry a ton more cargo and still takeoff or land within 640ft (History Net, 2009).

Figure 3. Burnelli CBY-3 (Wikipedia, 2010)

CBY-3 in flight over Long Island, NY

Figure 4. CBY-3 In flight (The Burnelli Company, 2009)

The Junker 30, developed by the Germans in 1930, was initially used for airline transport. It used the basic principles of a BWB to carry passengers and cargo. Passengers were seated in both wings and down the fuselage. Initially the Junker 30 could carry 13 people but later was expanded to handle 17 more people by expanding the wing structure. Later the Junker 38, produced as advancement to the Junker 30, could carry 34 passengers (EADS, 2009). Only two Junker 38s were produced. After years of service with Lufthansa, one was incorporated by the Nazis in the late 1930’s as a troop carrier for the Luftwaffe. It was also converted into a bomber and used during WW II. During WWII the Junker 38 was destroyed in an air raid by the British.

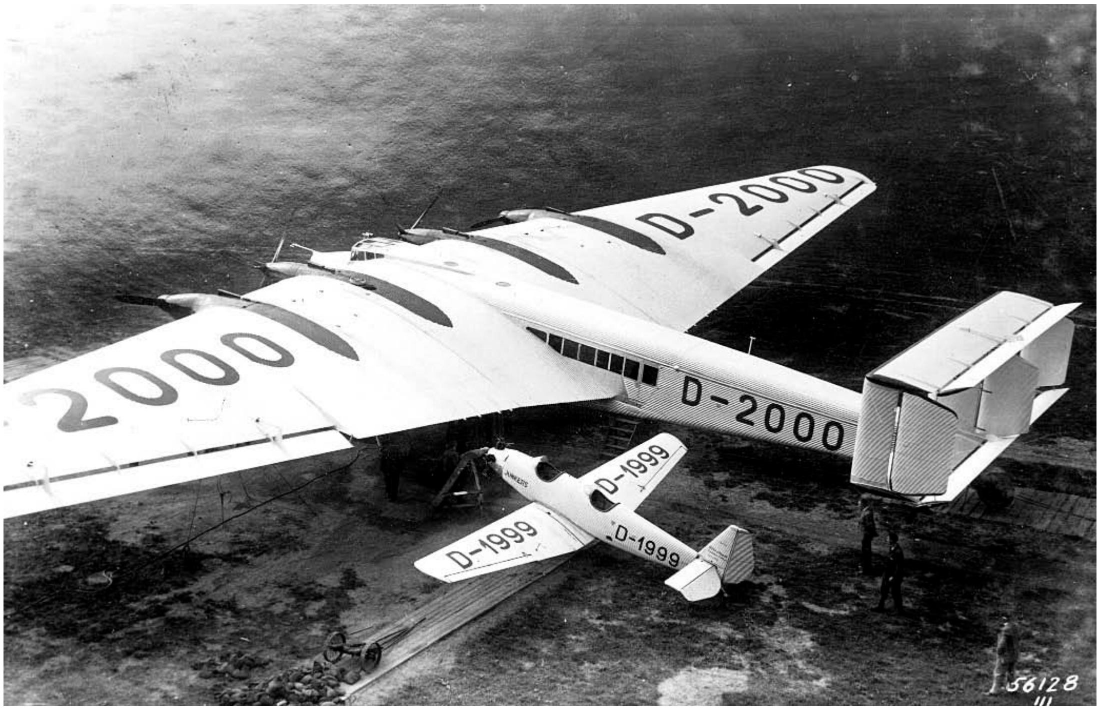


Figure 5. Junker G-38 (EADS, 2009)

During the late 1980s, NASA issued a request to the aeronautical industry to design a future airliner without any attachment to current or conventional design. NASA wanted companies to start with a clean slate to look at new ideas or technologies that could surpass the capabilities of current conventional designs. Figure 6 and 7 are pictures of the X-48B designed by Boeing, NASA and the Air Force Research Laboratory. It was built by Cranfield Aerospace Ltd. in Great Britain, known for their expertise on building advanced, model airplanes (Smith, 2009). The X-48B was built exactly to Boeing specifications. The X-48B was designed as a test bed for BWB applications for future military and civilian use. Boeing wanted to use the design for future airliners while the military saw many possible applications to include the AF's next strategic airlifter. Note the engine placement above the aircraft body.

Figure 6. Boeing X-48B, (Marty Curry, 2008)

Figure 7. Boeing X-48B In flight, (Marty Curry, 2008)

Structural Analysis of the Blended Wing Body

Using a BWB type design for an aircraft poses many new questions and problems for the aerospace industry since it is a new and relatively unproven design. History shows that most analysis and development was conducted with conventional tube and wing designs, with variations (delta wings) to encompass supersonic flight as in the XB-70 developed by NASA and the USAF (National Museum of the USAF). Some of the areas that must now be studied include structural design and analysis, to include materials, flight control systems, engine placement and development and overall aircraft design. Not surprisingly, a large amount of research has already been conducted on many aspects of using a blended wing design for aircraft.

One of the earliest engineers to embrace the BWB concept was Dr. Robert Liebeck of Boeing. “He attained world recognition starting in the 1970s with his novel designs for high-lift airfoils, referred to by the aeronautics community as the ‘Liebeck airfoils’” (Henry Samueli School of Engineering). He first worked for McDonnell Douglas and started researching BWB design before Boeing bought McDonnell Douglas. Dr Liebeck is considered to be the co-developer of the BWB and is also a Senior Fellow at The Boeing Company (Henry Samueli School of Engineering). Dr. Liebeck has written many research papers based on the BWB and the possibilities for the design in future aircraft.

One of the major articles that Dr. Liebeck wrote with fellow colleagues at Boeing was the BWB Subsonic Commercial Transport. This research paper helped set the frame for BWB design and research for the aerospace industry. The paper compared a conventionally-designed, double-decker aircraft to a BWB aircraft to carry 800 passengers over a 7000 Nm range at Mach speeds (0.85) (Liebeck, Page, & K, 1997). Five key performance factors were used: fuel burn,

takeoff weight, operating empty weight, total thrust, and lift to drag ratio. For each factor, the BWB was deemed superior, as shown in Table 1.

Fuel Burn	27% lower
Takeoff Weight	15% lower
Operating Empty Weight	12% lower
Total Thrust	27% lower
Lift/Drag	20% higher

Table 1. Resulting Improvements (Liebeck, Page, & K, 1997)

Liebeck first starts with a history of aircraft design and shows that for the first half of the century large design growth occurred between the Wright Flyer of 1903 and Boeing B-47 43 years later. The second half of the century saw no major growth in technology concerning new innovative types of designs. NASA decided to fund a study at Boeing to research the BWB design. NASA requirements for the aircraft are shown in Table 2.

800 passengers hi 3-class seating
7000 nautical mile range
0.85 cruise Mach number
11,000 foot takeoff field length
Composite primary structure
Advanced ducted propeller engine technology
2020 entry into service

Table 2. NASA Design Requirements (Liebeck, Page, & K, 1997)

After the design parameters were set, the interior volume was determined based on the size of an average person and the number of people. This total volume was then used to determine the shape of BWB body. Liebeck found that with a cylindrical disc as the body compared to a tube design the wetted area of the BWB was 14,300 ft^2; a 33% reduction. “The fuselage is also a wing, an inlet for the engines, and a pitch control surface” (Liebeck, Page, & K, 1997). This was the foundation for designing the BWB aircraft and the next step was to develop a realistic airplane configuration from this canonical shaped disk. The resultant airplane configuration is shown in figure 8.

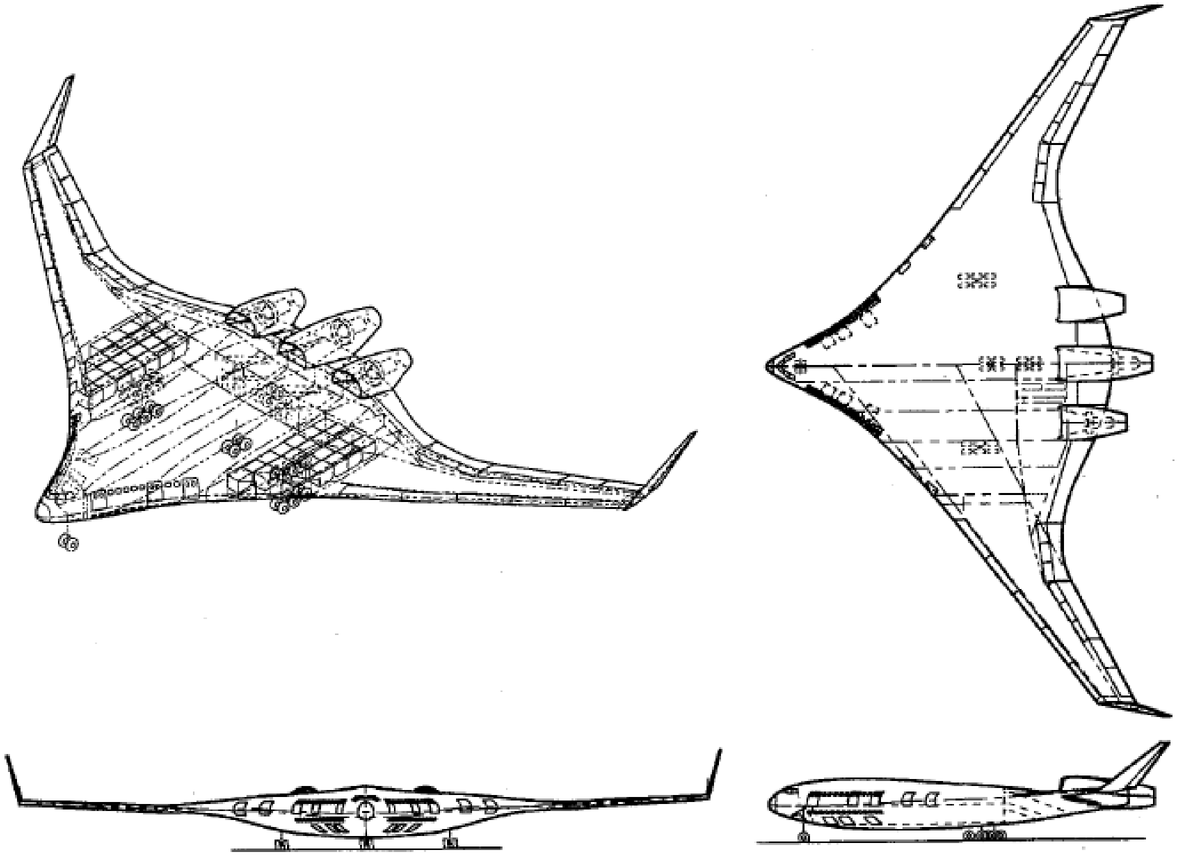


Figure 8. Current BWB Configuration (Liebeck, Page, & K, 1997)

The figure 8 configuration of the BWB poses new challenges for aircraft design. Liebeck listed eight areas that must be addressed: wing sizing, aerodynamics, stability and control, propulsion, structure, interior, safety and environment, and performance. The requirements for the wingspan were based on the initial design parameters and found to be 280 feet. The wing loading for the BWB was only 100 pounds per square foot (psf) compared to conventionally-designed, aircraft which are much closer to 160 psf. Liebeck states that this is due to much of the wing being blended into the aircraft's body. For aerodynamics, Navier Stokes computational fluid dynamics analysis was performed to identify lift coefficients and thickness-to-chord ratio over the wing span. This was to ensure a reasonable angle of attack would be used during cruise and that enough lift was being generated over the thick body section due to payload

considerations.   A follow on to the aircraft's aerodynamics was stability and control. Liebeck highlighted, "to trim the BWB with only centerbody reflex requires a statically unstable airplane." Liebeck found that keeping wing loading down required no drastic high-lift device. They found that a leading edge slat with simple hinged flaps for the trailing edge, was necessary (Liebeck, Page, & K, 1997). Multiple small scale models were also tested to analyze slow speed flight characteristics and were flown "successfully with excellent handling qualities" (Liebeck, Page, & K, 1997).

The next area analyzed was BWB propulsion. Multiple engine designs were considered. The engines were located aft and above to balance the aft center-of-lift for the wing. Liebeck also tried to set the engines somewhat inside at the aft end of the airplane to create boundary layer swallowing resulting in lower fuel burn because it reduces the ram drag at the engine inlet (Liebeck, Page, & K, 1997). One problem with this design was making sure than uniform air flow reaches the face of the fan blades for the compressor. Based on all these factors, Liebeck conducted an engine installation down select study to determine which engine configuration would work the best. His results found that an upper S-bend configuration compromised best among all the factors. This design met foreign object debris and noise avoidance criteria, adequate center of gravity range and ditching characteristics (Liebeck, Page, & K, 1997).

For the structure and interior of the BWB, Dr Liebeck knew he wanted to use the passenger cabin as a wing bending structure. Liebeck states this distributes the BWB's weight along the span in a more optimal fashion compared to a conventional design. A large amount of the BWB will depend on composite materials for its construction and one of the major challenges was developing the structural concept for the center body based on necessary cabin pressures and wing bending loads. In a conventional design, a tube handles cabin pressures very

well with no real problems. Liebeck proposed several solutions including a 5 inch thick sandwich, deep hat stringer structural shell, or a deep skin/stringer arrangement. Based on the structure and NASA requirements, a double-deck BWB interior was found to best utilize the camber of the center body. Liebeck looked at many different interior configurations but found that the multiple bay configuration best utilized the interior volume while providing structural rigidity as shown in figure 9. One problem that Liebeck does not discuss with this design was the lack of windows. This could pose a human factors engineering problem for designers; passengers may not accept no windows in the passenger bays. He also does not discuss the off-axis rolling motion of the aircraft as it turns and banks and the effects that it could have on passengers.

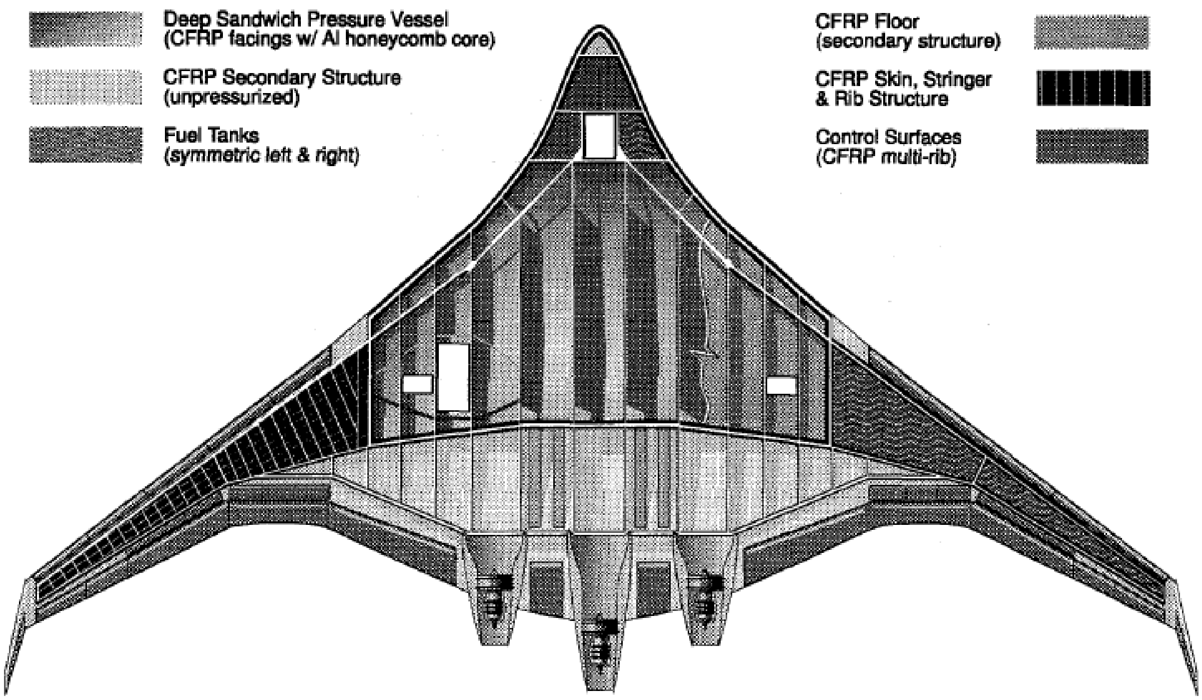


Figure 9. BWB Structural Layout (Liebeck, Page, & K, 1997)

Liebeck cited many design attributes that contribute to a safer aircraft. This included the placement of the engines and if, given catastrophic failure, whether fan blades would hit

passengers. Also, with the fuel bays separated by the cargo bays a safer distance is maintained in event of a fire. Liebeck cited a stronger structure aiding in ditching scenarios. Finally, Liebeck toutes much lower noise levels because of engine placement and a lower carbon footprint due to much lower fuel burn rates.

The last factor that Liebeck cited was performance. A conventional designed aircraft with the same NASA requirements and technology was designed to directly compare the BWB to a conventional design. Table 3 compares the BWB and conventional baseline. The BWB shows advantages in a lower takeoff gross weight, lower operating equipment weight, lower fuel burned, higher lift to drag ratio and higher wing area. Some of the disadvantages include a larger wingspan and lower thrust-to-weight ratio, but this is due to the BWB only using 3 engines compared to 4 for the conventional design.

		BWB	Conventional
Passengers	n.d.	800	800
Range	nmi	7000	7000
TOGW	lbs	823,000	970,000
OEW	lbs	412,000	470,000
Fuel Burned	lbs	213,000	294,000
L/D @ Cruise	n.d.	23	19
Wing Span	ft	280	235
Wing Area (trap)	sq ft	7840	6100
Total Thrust	lbs	3 x 61,900	4 x 63,600
T/W	n.d.	0.226	0.262
TSFC	(lb/hr)/lb	0.466	0.466

Table 3. Performance Comparison for BWB/Conventional (Liebeck, Page, & K, 1997)

Dr. Liebeck concludes the paper by admitting that the performance advantage for the BWB is unusual, even unprecedented, in the aircraft industry. He gives credit to the design itself and not so much to traditional advancements in technology. Liebeck states that the BWB configuration itself is the new technology and that the aircraft could be built today with current

engines and aluminum.   Even though many advantages were identified in his research, he realizes that many challenges, as in all technical disciplines, need to be addressed some of which will require creative solutions (Liebeck, Page, & K, 1997).

Liebeck (2004) provides a more encompassing explanation of the advantages and the challenges of the BWB concept. New additions are highlighted from the research between 1997 and 2004. One of the new findings included a modular approach to looking at various sizes of BWB aircraft, from 200 passenger variants all the way up to 600 passenger variants (Liebeck R. H., 2004). Liebeck divided this paper into 3 sections based on the development having three distinct phases: formulation, initial development and feasibility. He also provides a description on the current Boeing BWB baseline airplane.

The formulation was mostly covered in his previous paper in 1997, but Liebeck highlighted seven different design constraints; volume, cruise deck angle, trim, landing approach speed and attitude, buffet and stall, and two new areas, power for control surface actuation and manufacturing. The BWB is designed as an unstable aircraft requiring many different control surfaces based on the unique tailless configuration so power for the control surface is important. Dr. Liebeck illustrated the importance of sizing the hydraulic system to meet the flight control requirements. The problem becomes unsolvable if enough power is not attainable for the hydraulic system based on high bandwidth requirements (Liebeck R. H., 2004). The problem is unsolvable only if a higher deck angle is required to produce a stable aircraft thus making the angle-of-attack unacceptable at cruise speeds. For manufacturing, the advanced complex, three-dimensional shape needed to satisfy aerodynamic requirements could require very costly manufacturing techniques, which would pose a problem. Liebeck states that smooth, curved surfaces must be found to satisfy these constraints and keep costs at a minimum.

For initial development and feasibility, Liebeck did not highlight any new information from his previous research. Based on three different studies with NASA, Boeing decided that the 800 passenger, 7000 Nm range BWB aircraft was inappropriate for the in-house evaluation of the BWB (Liebeck R. H., 2004). One of the reasons was the lack of a market forecast for a 800 passenger aircraft. This led Boeing to develop the BWB-450 Baseline Airplane.

Multiple areas were studied for the BWB-450 which included: design requirements and objectives, configuration, multidisciplinary design optimization, aerodynamics, stability and control, propulsion, structure, performance and environment. The size of the BWB-450 was considered nominal and readily comparable to current aircraft like the Boeing 747 and Airbus 340. An important aspect was size requirements for airports which based the wingspan limit on 262 ft. (Liebeck R. H., 2004) The configuration was based on a three class seating arrangement with all cargo being carried underneath the main deck. The wingspan was 249 ft and could easily fit in the Class VI airport box (80m) (Liebeck R. H., 2004). The airport box is the parking space required for an aircraft.

Due to the unconventional design of the BWB-450, Boeing had to develop new software and coding to evaluate and develop the design of the BWB-450. WingMOD was developed and is used to measure multiple forces, lift, drag and help size the structure based on those forces (Liebeck R. H., 2004). Liebeck states the final output is an optimized design that is meets all design mission requirements with minimum takeoff gross weight. The aerodynamics of the aircraft were closely tied to the results of WingMOD. This resulted in a new class of transonic airfoils for the centerbody (Liebeck R. H., 2004). Liebeck also stated that the chord for the centerbody and outer wing were increased to provide better buffet characteristics and reduced pressure drag. Overall, many changes were made to the BWB-450 platform. The stability and

control of the BWB-450 was trimmed to provide a stable center-of-gravity with all the control surfaces faired, with no induced drag penalty (Liebeck R. H., 2004).

One significant change for the BWB-450, compared to the original concept, concerned the propulsion and how the engines would be situated on the aircraft. Liebeck decided the technological risk of setting the engines partially inside the aircraft was too great, therefore a more conventional approach of engine on pylons was used. This resulted in an increase in drag from the wetted area of the engines, but accounted for only 4% increase which was deemed acceptable for the design (Liebeck R. H., 2004).

For the structure design, the primary figures of merit were weight and cost. Liebeck explained the internal pressures on the skin and the bending moments associated with the skin. The end result "is an unusually rugged passenger cabin that weighs little more than a conventional fuselage" (Liebeck R. H., 2004). Liebeck detailed the materials that would be used for the aircraft with composites a necessity for the body of the aircraft due to weight concerns. It was interesting to note that even using composite material for the body made the BWB body heavier compared to a conventional design even though the whole BWB aircraft was much lighter (Liebeck R. H., 2004).

Liebeck also discussed performance and environmental impacts of the BWB-450. He compared the performance of the BWB-450 to the new Airbus 380-700 based on 480 passengers and a range of 8700 Nm. Boeing found a 32 percent lower fuel burn per seat compared to the A380 (Liebeck R. H., 2004). Equivalent engine technologies were used, but the advantage for the BWB-450 was due to three engines needed compared to the four engine A380. Finally, Liebeck again found, a lower carbon footprint and reduced noise pollution for the BWB-450.

Dr. Liebeck concludes the article with four unique opportunities and challenges of the BWB configuration. The first, manufacturing part count was illustrated to show a 30% reduction of parts needed for the new aircraft. Liebeck stated there are 90 degree loaded structures at the empennage and wing and no fillets. Also, the trailing edge control surfaces are hinged with no track motion and no spoilers (Liebeck R. H., 2004). All this contributes to fewer parts in the manufacturing process (a key component of reducing the design for assembly or design for manufacturing costs).

Liebeck also addressed the scalability of the BWB. The aircraft can be increased laterally as opposed to longitudinally. This makes the design very modular and Liebeck provides an example of aircraft ranging from 250 to 550 passengers. Figure 10 illustrates a wide range of aircraft types based on the BWB configuration size ability. A major goal was to maintain the entire wing common for any size aircraft. The cockpit could also remain the same and commonality of the engines would also be possible (Liebeck R. H., 2004). Liebeck illustrated the savings for airline companies by listing all the interior sections that would remain the same for different size aircraft, such as galleys or lavatories. Liebeck did state that the tradeoff between cost and performance, based on this aircraft family concept still requires thorough evaluation.

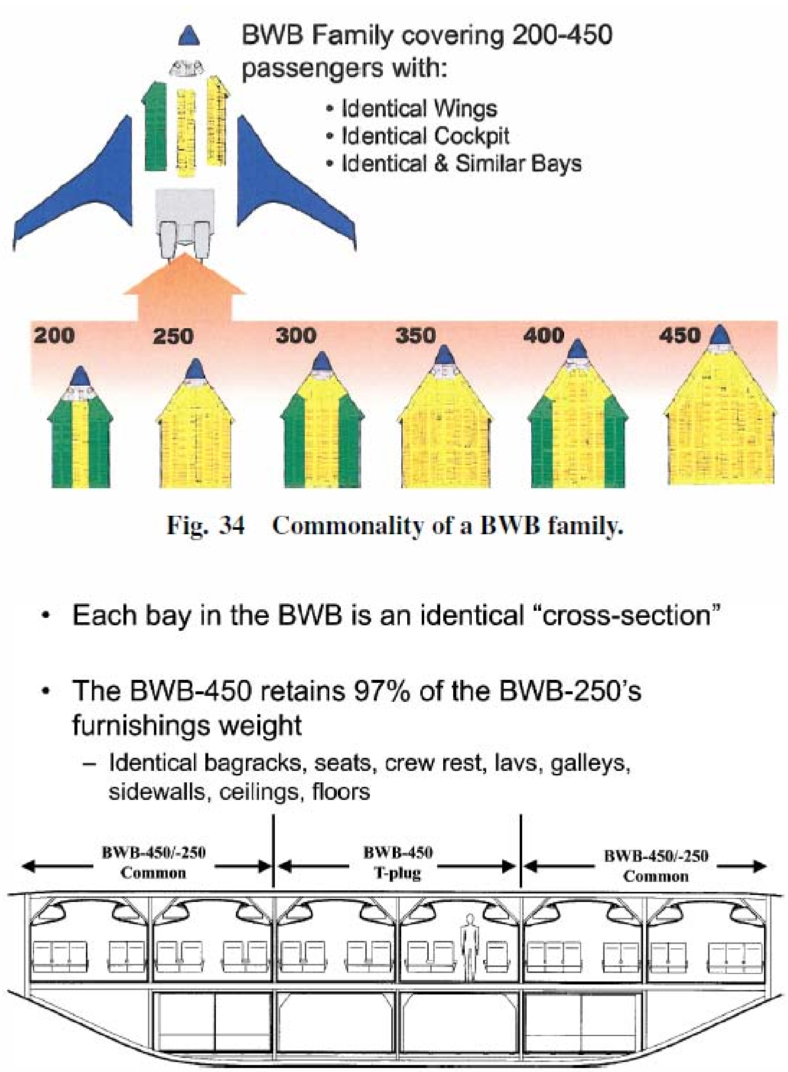


Figure 10. Commonality of a BWB Family (Liebeck R. H., 2004)

Speed was the next issue. Liebeck tested Mach numbers between 0.8 and 0.95. Engineers knew that in order to achieve a higher Mach number, the wing sweep would have to increase (including the chord). This, however, would increase weight. Based on these results, Liebeck concluded that Mach 0.9 would be the best cruise speed but the economic value of speed and time must be determined before a final design cruise speed is established.

Human factors engineering concerns included passenger acceptance, ride quality and emergency egress. None of these factors were addressed in Liebeck (1997). Based on the

multiple cabins and vertical walls, passengers would be afforded more space but would lack windows. Liebeck stated that digital screens could be used to display virtual outside pictures using video cameras. Liebeck also discussed ride quality concerning the lateral offset of passengers compared to conventional B 747s. Flight simulations were used for both aircraft in takeoff and landing configuration with 35 knot crosswinds. Liebeck found that the lateral and vertical G-levels were comparable for the worst seats in both aircraft. Lastly, Liebeck addressed emergency egress for the BWB configuration. Each cabin has a main door at the front of the aisle and there are four cross aisles, with an emergency exit through the aft pressure bulkhead at the back of each aisle (Liebeck R. H., 2004). With all these exits, Liebeck stated that any passenger will have a direct view of one or more exits, but did recognize the need for the Federal Aviation Administration to establish new criteria for larger, unconventional aircraft.

Liebeck concluded with a list of issues facing the BWB configuration. This list was actually from the 1950s development of the DC-7 to the DC-8 and is shown in table 4.

Table 3 Issues and areas of risk (from Douglas Aircraft Co., 1955)

• Complex flight control architecture and allocation, with sever hydraulic requirements
• Large auxiliary power requirements
• New class of engine installation
• Flight behavior beyond stall
• High floor angle on take off and approach to landing
• Acceptance by the flying public
• Performance at long range
• Experience and data base for new class of configuration limited to military aircraft

Table 4. Issues and Areas of Risk (Liebeck R. H., 2004)

Current Research on BWB

Since the acquisition of McDonnell Douglas, Boeing has invested significant resources and money into developing a BWB. As the X-48 program continues with C, and future D,

models, Boeing is developing the EET. The EET is a similarly-sized aircraft compared to a C-17, although the wingspan is 22 feet wider, yet the aircraft length is 64 feet shorter. The EET is designed to carry 19 463L pallets with only one height restricted to 70 inches, because it is located on the ramp. With the BWB design, the interior volume of the aircraft is better utilized compared to a C-17 or C-5 because there is minimal wasted space between a full pallet and the top of the cargo bays. This could pose some limitations on over or outsized cargo. Due to the wide body of the BWB, it has three cargo compartments with the center being the longest as shown in figure 11. The side compartments could be utilized for passenger requirements. This configuration could also pose delays in loading and unloading of the aircraft. Normally, pallets are loaded straight into or off current airlift aircraft, but with the BWB aircraft it may be a more complex unloading process. Most likely, the aircraft will still have one ramp and door at the rear of the aircraft and not one for each cargo-holding section. It would probably be too complex, or pose a weight problem, having a ramp and door for each cargo section. With only one ramp and door, cargo for the side compartments would be loaded through the ramp and door then turned or slid through to the side cargo holds. This would require omni-directional rollers for the cargo floor (similar to the C-17) or a more complex motorized system. The loading and unloading of the aircraft is important because it helps determine the ground time for the BWB EET, which affects overall mission time.

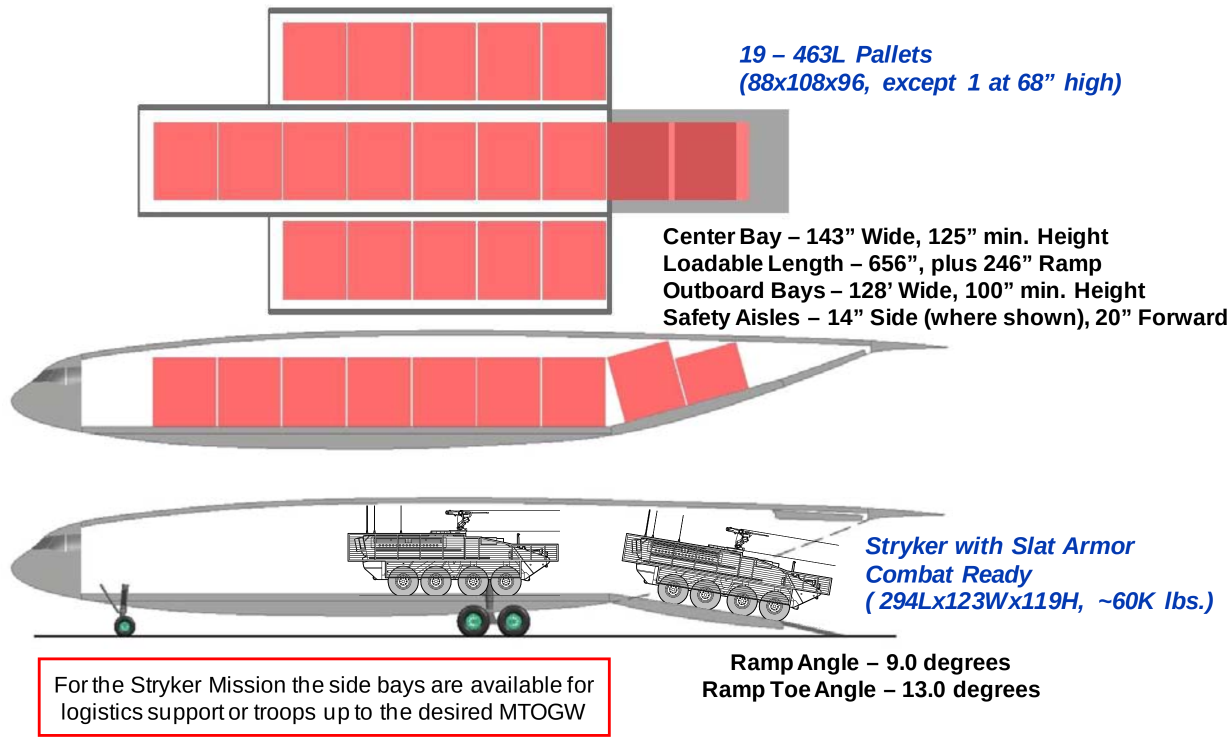


Figure 11. Boeing BWB EET Configuration, (Skorupa, Blended Wing Body BWB, 2009)

The BWB EET is designed to take rolling stock like the Army’s Stryker combat vehicles. Based on the payload configuration, the EET design load is 80,000 pounds with a maximum load of 115,000 pounds of cargo. For loading and unloading cargo, a rear ramp would be the primary means but front loading might be possible, like on the larger global transport in figure 12.

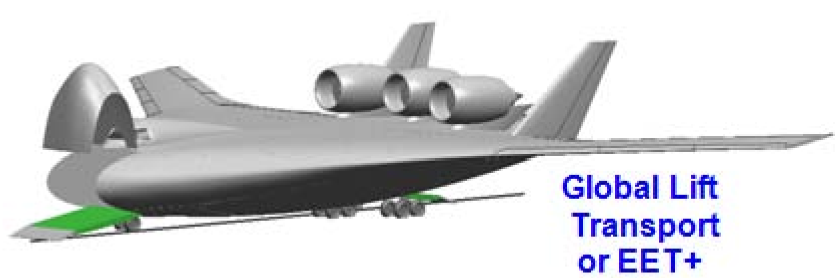


Figure 12. Boeing Global Lift Transport (Boeing, 2009)

To keep the EET within the wingspan of the C-17, it could be designed with folding wings, similar to Navy aircraft on aircraft carriers. Figure 14 shows the folding wing design. Also, with the folding wings and a much shorter aircraft length the footprint of an EET would be smaller than a C-17, thus reducing the airfield infrastructure required to park the same amount of aircraft. Without folding wings, the wingspan is 22 ft wider than a C-17 but the aircraft is still much shorter than the C-17 as shown in figure 13.

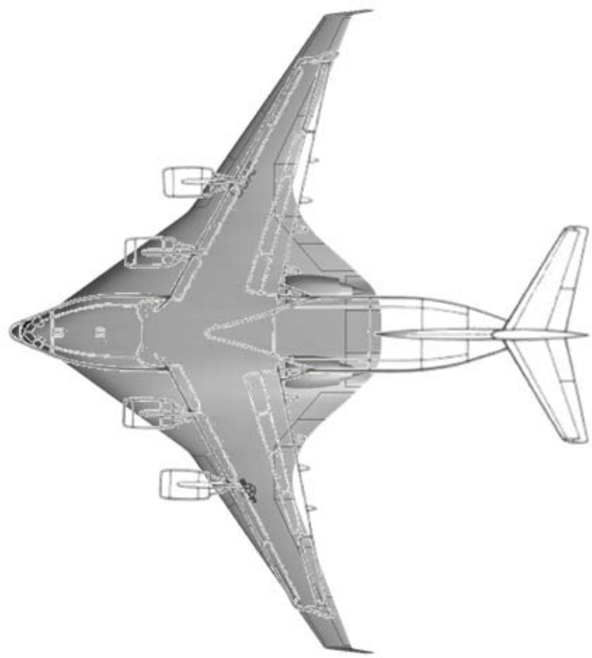


Figure 13. C-17/BWB EET Comparison (Boeing, 2009)

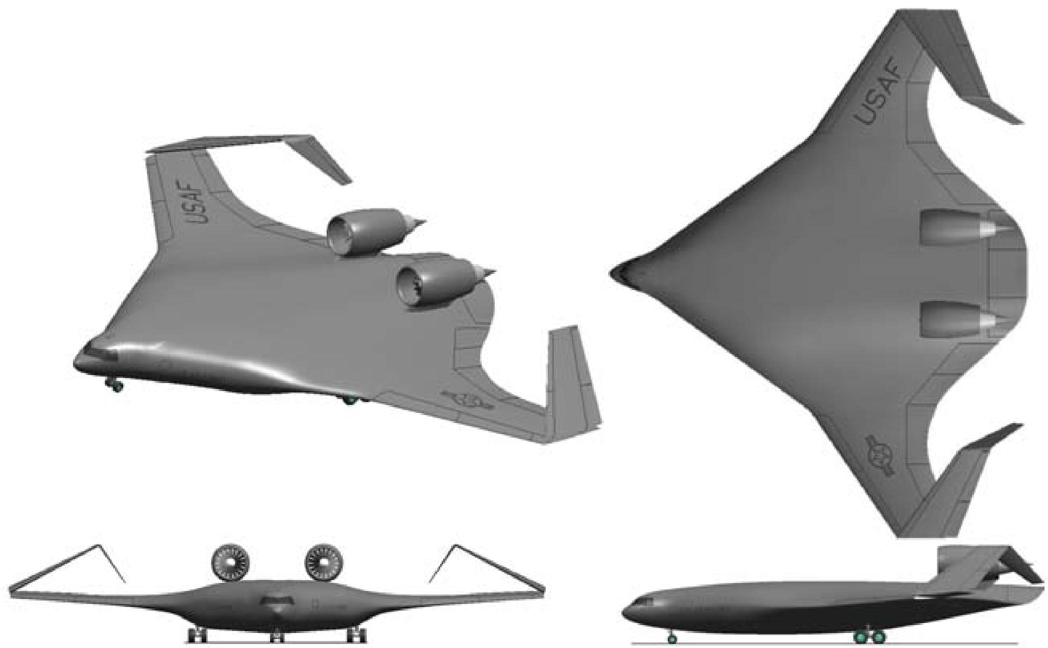


Figure 14. Boeing BWB EET Profiles (Boeing, 2009)

Another important aspect of the EET and the BWB is the scalability of the aircraft. Since the BWB is a modular type design, it can be expanded or shrunk to meet military needs. The basic wing structure would remain the same and the cockpit would also be interchangeable with different sized EETs. This would reduce training costs and time for military aircrews to learn and switch between different sized aircraft. The center of the aircraft would be increased to include more cargo bays as depicted in figure 15. A big advantage for this type of modular design is production cost reduction and further savings in research and development because multiple different sizes or types of aircraft could be produced. Another commonality of the BWB is the propulsion systems used. For the EET, two engines are used but for a larger C-5 type, EET 3 engines could be used. Based on the size of the aircraft, a different number of engines are used to produce the needed thrust. Using the same type of engine, regardless of quantity, further reduces maintenance costs across different fleets of aircraft.

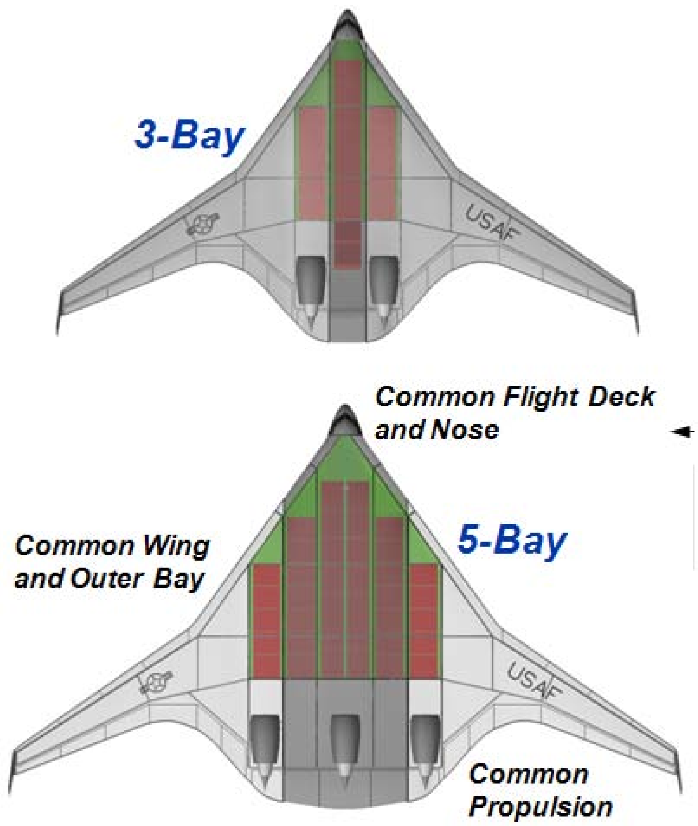


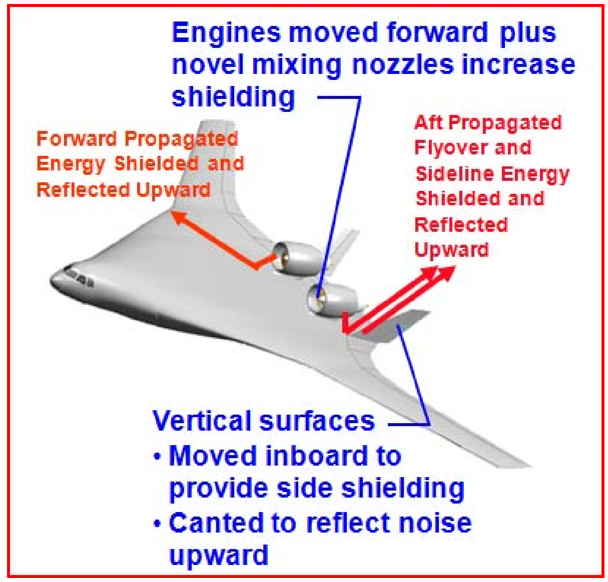
Figure 15. Boeing BWB Modular Cross Sections (Boeing, 2009)

Based on the research and development for the X48 program, the next step for the BWB is a manned demonstrator that Boeing plans to fly in approximately 2-3 years. It will be larger than a C-130, with a max takeoff gross weight of 165,000 lbs. The demonstrator will have a 134ft wingspan and will be approximately 30ft long. NASA, the AF Research Labs, and DARPA will be involved in the development of the BWB manned demonstrator. The manned demonstrator will be able to fly above Mach 0.9 and the flight program is planned for 2 years of testing. An important aspect of the manned demonstrator will be composite material tests. This will tie into the structural testing needed for the aircraft before it takes flight. Once the flight testing is complete, the engine development program will begin in approximately 2017. If research and development continues on track, Boeing plans to have a BWB airlifter operational in the first part of the 2020's.

Noise Reduction

Boeing stated that not only will the BWB EET reduce fuel consumption but it will also reduce noise pollution. This is important for a couple of reasons. Firstly, noise reduction is becoming more and more important at AF bases, as cities and towns encroach upon the base. This would reduce noise complaints and help foster good will with local communities and governments. This will also help meet future Federal Aviation Administration noise abatement goals that are sure to increase restrictions on noise.

Secondly, and more importantly, noise reduction helps with the stealth capability of an aircraft. Even if a weapon system is invisible to radar, it can still be seen or heard with the human eye and ear. The quieter the aircraft the less noticeable it is during its mission into a combat zone. Boeing developed the follow on to the X-48B, the X-48C, to study the effects on noise reduction due to engine placement and possible fuel reductions. The basic design of the blended wing locates the engines above and rear of the body. This placement keeps the engine noise above the aircraft. In studying the X-48B, Boeing, NASA and the AFRL found that sound waves are deflected between the large winglets further keeping the waves from extending out from the aircraft to the sides. Based on this observation, Boeing decided to move the winglets in towards the engines to further shield and deflect sound waves straight above the aircraft as shown in the figures 16 and 17.



Figures 16 and 17. Boeing X48C Vertical Stabilizer Placement

Boeing's desire for the BWB EET is to reduce noise levels 52 decibels below NASA's 1997 goal. Boeing's goal with the X-48C is to reduce noise levels by 40 decibels below stage 4. Stage 4 levels are currently set 10 decibels below stage 3 by the Federal Aviation Agency (FAA) and took effect in 2006 (Gilbert, 2004). Figure 18 describes the 3 base levels for noise classification by the FAA. With these low numbers, it will be very difficult for adversaries to hear and identify BWB aircraft on the ground or in the air. The X-48C demonstrates the advantages of noise reduction and the possibilities to meet future requirements.

Stage 1
A Stage 1 noise level means a take-off, flyover, or approach noise level greater than the Stage 2 noise limits.

Stage 2
Stage 2 noise limits for airplanes regardless of the number of engines are as follows:

- **For Take-off:** 108 EPNdB for maximum weights of 600,000 pounds or more, reduced by 5 EPNdB per halving of the 600,000 pounds maximum weight down to 93 EPNdB for maximum weights of 75,000 pounds and less.
- **For Sideline and Approach:** 108 EPNdB for maximum weights of 600,000 pounds or more, reduced by 2 EPNdB per halving of the 600,000 pounds maximum weight down to 102 EPNdB for maximum weights of 75,000 pounds or less.

Stage 3
Stage 3 noise limits are as follows:

- **For Take-off:** airplanes with more than 3 engines 106 EPNdB for maximum weights of 850,000 pounds or more, reduced by 4 EPNdB per halving of the 850,000 pounds maximum weight down to 89 EPNdB for maximum weights of 44,673 pounds or less.
- **For Take-off:** airplanes with 3 engines 104 EPNdB for maximum weights of 850,000 pounds or more, reduced by 4 EPNdB per halving of the 850,000 pounds maximum weight down to 89 EPNdB for maximum weights of 63,177 pounds or less.
- **For Take-off:** airplanes with fewer than 3 engines 101 EPNdB for maximum weights of 850,000 pounds or more, reduced by 4 EPNdB per halving of the 850,000 pounds maximum weight down to 89 EPNdB for maximum weights of 106,250 pounds or less.
- **For Sideline:** regardless of the number of engines 103 EPNdB for maximum weights of 882,000 pounds or more, reduced by 2.56 EPNdB per halving of the 882,000 pounds maximum weight down to 94 EPNdB for maximum weights of 77,200 pounds or less.
- **For Approach:** regardless of the number of engines 105 EPNdB for maximum weights of 617,300 pounds or more, reduced by 2.33 EPNdB per halving of the 617,300 pounds maximum weight down to 98 EPNdB for maximum weights of 77,200 pounds or less.

Figure 18. FAA Noise Stage Levels (Palm Beach International Airport, 2009)

Fuel Reduction with BWB

Testing on the X-48B, and now the X-48C, have shown that a 25-30 percent fuel reduction is possible. With X-48C, further fuel reduction is taking place based on the new placement of the vertical winglets and reducing the number of engines from three to two. By reducing the number of engines, the fuel burned is further reduced. Mr. Skorupa of Boeing stated that the goal of the BWB design and EET is to reduce fuel burn by a total of 60 percent (Skorupa, Senior Manager, Strategic Development, Advanced Global Mobility Systems, Advanced Systems, 2009). The BWB configuration accounts for approximately 30 percent but Boeing plans on engine technology and materials to account for the other 30 percent. In figure 18, Boeing demonstrated the fuel savings for AMC if only 40 percent of mobility aircraft were able to achieve a 50 percent increase in fuel efficiency. Potential savings could be 2 billion a year. Since the C-17 is the largest user of fuel for AMC, replacing them with BWB EET could make even a larger impact.

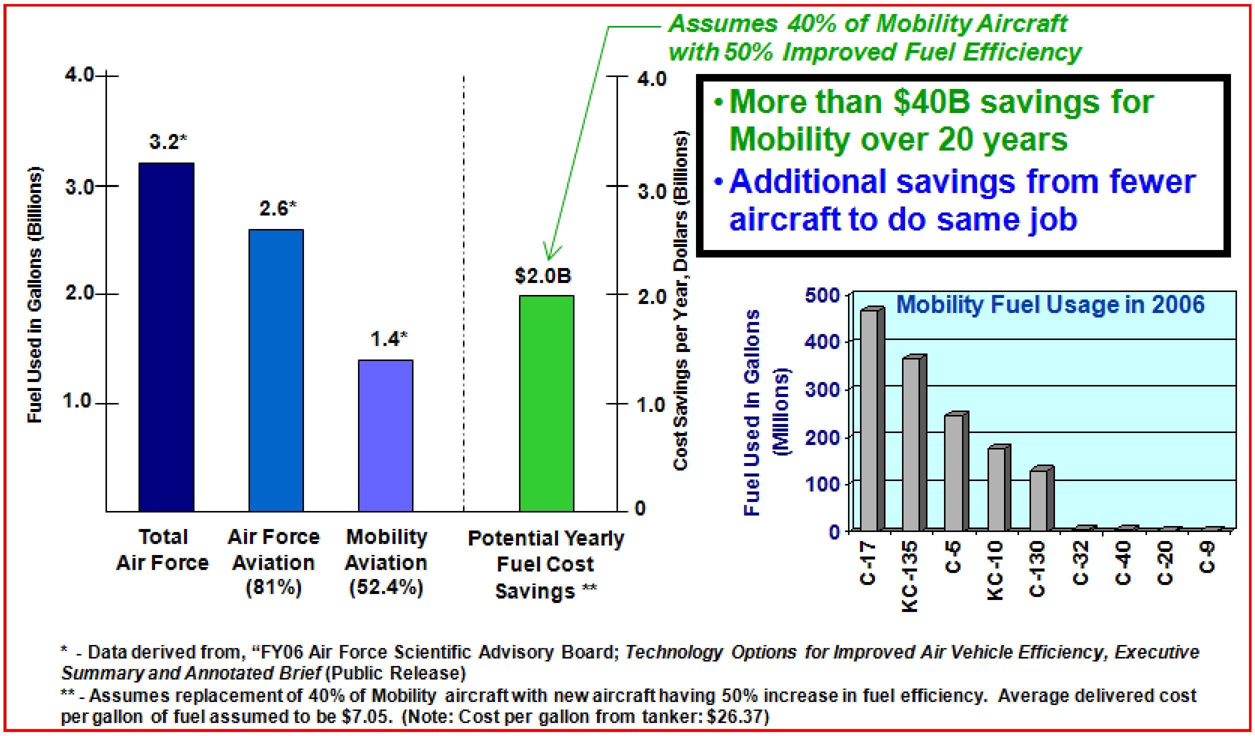


Figure 19. Boeing Proposed Fuel Savings (Skorupa, 2009)

According to Hodges (2009), NASA's goals are even more demanding. NASA wants an airplane that is silent and sends no carbon into the atmosphere. NASA is truly talking about an aircraft with net zero carbon fuels. These fuels would be biofuels that could be made from algae where the algae consumes carbon from the atmosphere and then when the fuel is burned they are released back into the atmosphere creating net zero carbon. This would help reduce the countries dependency on fossil fuels and foreign countries. NASA plans on a phased approach and admitted that the most likely design for this future aircraft will a BWB configuration (Hodges, 2009). Phase one will concentrate more efficient engines and the possibility of different fuels. No matter what fuel is used engine technology will play a large part in concert with a BWB configuration to meet the nation's goal for a significant reduction in fuel consumption.

Requirements for new C-X

The BWB concept and the EET developed by Boeing are very important concepts for AMC and the future C-X. The C-X will be the next generation long-range transport. (U.S. Air Force, HQ AMC/A8XPL, 2009) Realizing how long that it takes to develop and field a weapon system the AMC Commander has stated "Now is the time to begin planning for the follow on global airlift aircraft, the C-X" (U.S. Air Force, HQ AMC/A8XPL, 2009, p. 32). The C-17 took 14 years from program decision to putting an aircraft-on-ramp, as stated in the 2010 AMMP. With the length of weapon system's development, it is important to develop these capabilities now for the C-X. The BWB EET with its modular design is intended to meet all AMC requirements for the C-X. Below is the current list of capabilities needed for the C-X from the AMMP 2010.

"The C-X will incorporate a number of core enabling capabilities:

1. Advanced avionics to permit all weather operations independent of ground based navigation aids.

2. Automated air refueling to permit unrestricted global range.

3. Capability to rapidly load and unload cargo via a rear cargo door and ramp without requiring specialized materials handling equipment.

4. Ability to conduct combat offload procedures.

5. Capability to air drop materiel and personnel.

6. Capability to operate in the low-to-medium 2040 threat environment (using onboard and off board systems to detect and counter infrared, radar, and electro-optical guided surface to air missiles and directed energy weapons).

7. Fuel efficiency improvements from a combination of advanced engine technologies, increased use of light composite materials to decrease aircraft weight, and improved aircraft aerodynamic design."

Although the BWB EET will need to be designed to meet or exceed each capability, it will not be easy. Advanced avionics is a must for the flight control systems as well as all other systems, like all weather capability. Automated air refueling should be the standard for all future aircraft. Boeing should not be challenged by either of these requirements. The next requirement of rapid unloading and loading of the aircraft could be a challenge. Boeing will have to develop a system without adding weight and complexity to the aircraft while still maintaining the design of the blended wing body. The ability to conduct combat offloads will depend on the ramp configuration of the BWB EET and its ground operating capability. The ability to airdrop materials will be probably be more dependent on the aircraft slow speed flight characteristics than the actual design of the aircraft although the amount of material to be airdrop could decrease based on the multi cargo compartment design. Since airdrop speeds are similar to takeoff and landing configurations, the airdrop capability should be accomplished since tests of the X-48B has gone very well. One of the Boeing/NASA test pilot that the "X-48B exhibited no unusual characteristics, and is a very nice airplane to fly" (Boeing, 2009). Next the ability to survive in medium threat environments will depend largely on what defensive system Boeing decides to incorporate in the BWB EET. Advanced laser systems, like LAIRCM (Large Aircraft Infrared Countermeasures) and future versions, will most likely be employed, but the real challenge will be the capability to avoid small arms fire and anti-aircraft artillery (AAA). Kinetic weapons like small arms and AAA have brought down more aircraft than Surface to Air Missiles (SAM), like the British C-130 that was brought done by small arms fire in 2003 near Bagdad. Future weapon systems, including the BWB EET, should study the advantages of designing armor into the aircraft to help protect crew and vital aircraft systems. This has helped many aircraft in combat.

The last capability, fuel efficiency, is where the Boeing's BWB EET will excel. Through the inherent design of the concept to advances in engine design and placement Boeing plans on reducing fuel consumption by 30 percent through the aircraft design and another 30 percent through engine technology and use of composite materials. The reduction in fuel consumption is becoming more and more important to AMC and could be a major reason for the BWB EET becoming the C-X.

The next step for framing the requirements for the C-X is for the Future Concepts Branch to outline the above basic capabilities in a Future Global Airlifter White Paper whose purpose will be to attain a unity of understanding and support for a future global airlifter. AMC will use this document as the basis to initiate an Intertheater Lift capabilities-based assessment leading to the first series of requirements documents necessary to field the C-X (U.S. Air Force, HQ AMC/A8XPL, 2009). Once the requirement documents are produced, then manufacturers, like Boeing, can then begin to fine tune the BWB EETs design to meet those capabilities.

III. Methodology

Acquisition professionals use many tools to develop new assets for the warfighter. Models normally applied by operations planners can offer valuable insight into the characteristics of a new aircraft. For this research project, the AMPCALC was utilized to evaluate mobility closure rates for Boeing's experimental C-X, Blended Wing Body Energy Efficient Transport (EET) aircraft. By using projected performance characteristics for the BWB EET (obtained from John Skorupa, Boeing's Senior Manager for Advanced Global Mobility Systems) in AMPCALC, the overall deployment capabilities of the BWB EET and C-17 were compared.

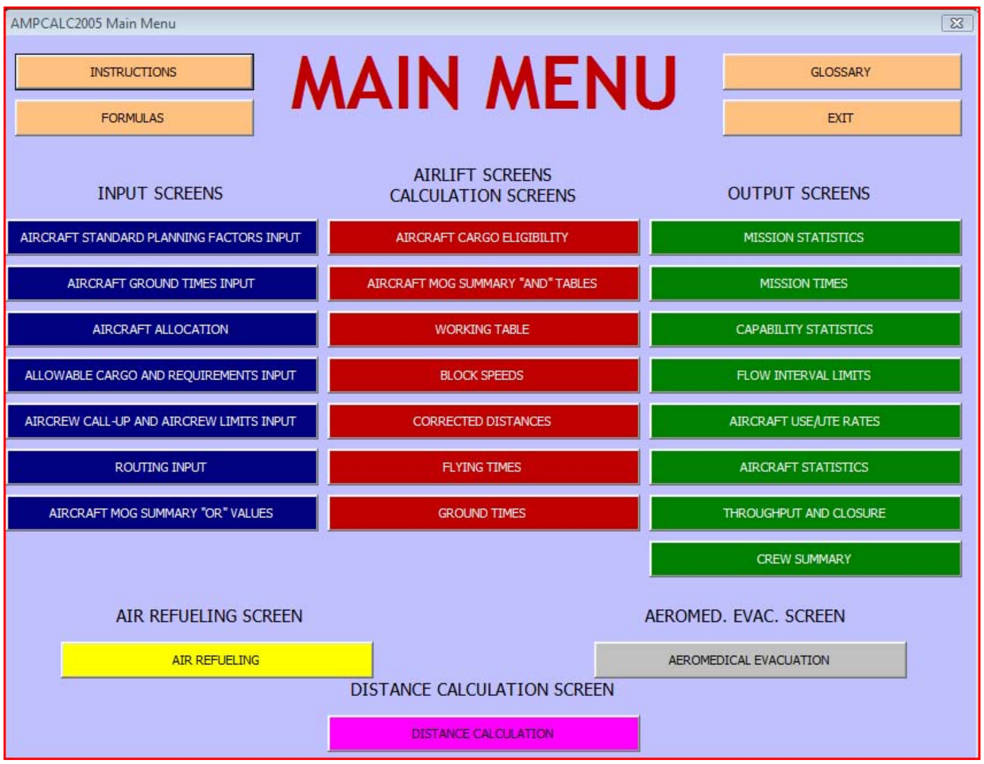


Figure 20. AMPCALC Menu

AMPCALC Model

AMPCALC gives planners an initial estimate on mobility requirements. It is an excellent starting point, but does not provide enough fidelity to make specific resource allocation decisions. The model has approximately 85 percent fidelity (Moore, 2009). All three primary mission areas of air mobility are modeled: airlift, air refueling and aeromedical evacuation. AMPCALC is Excel-based and comes pre-programmed with known performance data for all airlifters in the USAF fleet (except for the C-130), as well as four civilian aircraft. The maximum payloads and cycle block speeds are based on data in AF Pamphlet 10-1403. AMPCALC has four placeholders for new aircraft. One place holder was used to model characteristics for the BWB EET as the future C-X. The steps required for entering a new aircraft into the model can be complex, so not all variables were utilized for this research. Not only must the aircraft characteristics be provided, but some formula changes were required as well to properly model the BWB EET.

AIRCRAFT STANDARD PLANNING FACTORS INPUT

Aircraft (Type)	Act/AR PAA	ARC/UE PAA	Withhold Tng/Other	MC Rate	Avail for Use	MC Rate Factor 0=Off	1=On	# Pax w Cargo	# Pax w/o Cargo	% Cargo with Pax	Object Surge	Average Payload	Surge UseRate	Alternate UseRate	AMMP Payload	Alternate Payload	Planned Block Speed
KC-135	241	222	0	89%	412.07	100%	89%	0	46	100%	5.60	13.00	5.60	5.60	13.00	13.00	419
C-5	70	34	0	75%	78	100%	75%	51	51	100%	10.60	61.30	10.60	6.80	61.30	61.30	409
C-141	0	0	0	83%	0	100%	83%	11	120	100%	12.10	19.00	12.10	7.40	19.00	19.00	405
C-17	400	6	0	90%	365.4	100%	90%	11	90	100%	15.15	45.00	15.15	11.70	45.00	45.00	410
KC-10	57	0	19	93%	34.01	100%	93%	0	68	100%	12.50	32.60	12.50	7.90	32.60	32.60	434
DC-10	47	0	0	95%	44.65	100%	95%	0	180	100%	10.00	62.00	10.00	10.00	62.00	62.00	455
B-747F (Mix)	38	0	0	95%	36.1	100%	95%	7	335	100%	10.00	86.00	10.00	10.00	86.00	86.00	465
MD-11F	63	0	0	95%	59.85	100%	95%	0	315	100%	10.00	80.00	10.00	10.00	80.00	80.00	455
WBP Equiv	122	0	0	95%	115.9	100%	95%	0	335	100%	10.00	53.00	10.00	10.00	53.00	46.50	465
WBC Equiv	131	0	0	95%	124.45	100%	95%	0	0	100%	10.00	73.00	10.00	10.00	73.00	78.00	465
NBC	9	0	0	93%	8.37	100%	93%	0	0	100%	10.00	33.00	10.00	10.00	33.00	33.00	440
C-X	400	0	0	90%	360	100%	90%	0	0	100%	15.15	40.00	15.15	11.70	40	40	465
C-Y	0	0	0	90%	0	100%	90%	0	0	100%	0.00	0.00	0	0	0	0	409
NEW-3	0	0	0	93%	0	100%	93%	0	0	100%	0.00	0.00	0	0	0	0	405
NEW-4	0	0	0	93%	0	100%	93%	0	0	100%	0.00	0.00	0	0	0	0	410

MC Rate Factor ===> ON OFF 1
(0= Off,1= On)
Percent Avail Factor => 100% 100%
(Between 0% and 100%)

USE Rate Factor===> STD ALT 0
(0=STD,1= Alternate)
PAYLOAD Factor===> STD ALT 0
(0=STD or War,1=DesertStr./Alternate)

Block Speed Factor ==> STD ALT DIS1
0
(0=NewStd , 1=Alternate, 2= For distance related block

Table 5. AMPCALC Aircraft Standard Planning Factors Input Page

Data Sources

Data on Boeing's BWB aircraft came from their director of the Strategic mobility division of Boeing in Long Beach California, Mr. John Skorupa. The requirements for new the C-X came from the AMMP 2010 and Air Force A8 division for future requirements. Current requirements for the C-X were listed in the literature review.

To build the BWB aircraft into the AMPCALC model many assumptions had to be made and limitations were identified. There were multiple steps that were taken to build the new BWB aircraft or C-X into AMPCALC. These areas included aircraft payload capability, cargo inputs, block speeds, Utilization (Ute) rates, ground handling times, route structure used and comparable fleet size. The C-17 was analyzed to compare current strategic airlift aircraft to the BWB aircraft. Each one is explained in more detail.

Payload Capability

Boeing's EET was used as the model of the future BWB aircraft. Based on the desire to keep the new aircraft similar in size to the C-17, payload was limited by the size of the aircraft. The design payload for the BWB EET was 40 tons or 80,000lbs, with the max payload at 57.5 tons or 115,000lbs. The design payload is 5 tons less than a C-17 but the BWB EET can carry 19 full size 463rd pallets with one height restricted to 72 inches. This is due to placement on the ramp.

With payload capability, AMPCALC also requires a breakdown of how much bulk, oversized, and outsized cargo each aircraft can handle. This is a percentage of bulk cargo which equals the aircraft's outsized or oversized capability. Both the C-17 and BWB EET use 80% of its bulk capability to equal its outsized capability. In reality, the BWB EET may have a smaller

outsized capability since its interior volume is used more efficiently compared to the C-17. This factor will not make a difference for the tests, since only bulk cargo was utilized for this research.

Cargo Inputs

The bulk cargo used for the analysis was based on a scenario moving one heavy brigade, 3 light brigades and 12 fighter squadrons. Bulk cargo for these units adds up to 8230 tons. Each trial run used this tonnage to determine the closure day required.

Block speeds

The block speed used for the EET was 0.84 Mach, which is the same for the Boeing 747s used in AMPCALC. Boeing has stated that the BWB aircraft will cruise at approximately 0.85 Mach. Since the 747s block speeds were already calculated, and were more conservative, they were used for the BWB EET.

Utilization Rates

Utilization rate, or Ute rate, was not easy to calculate because some of the data that is used in determining the rate are based on historical data. Since the BWB EET would be a new aircraft, there is no data to help calculate the Ute rate. The Ute rate is the capability of a fleet of aircraft to generate flying hours in a day, expressed in terms of per Primary Authorized Inventory (PAI). The Ute rate typically only applies to long-term, large-scale operations such as OPLANS. (Air Force Pamphlet 10-1403) There are also two types of Ute rates: a surge and sustained Ute rates for wartime. The surge Ute rate is used for the first 45 days then the sustained Ute rate is

used, which more accurately matches a normal operations tempo. More detail on Ute rates can be found in AF Pamphlet 10-1403.

Without historical data for the BWB EET, a Ute rate based on the C-17 was used. Even though a new aircraft with the same size crew could probably perform at a higher Ute rate, there is no hard evidence to support that assumption. An equivalent Ute was decided on as 15.15, which was based on a surge Ute rate.

Ground Handling Times

The C-X's cargo bay has three sections: left, center and right, as opposed to a C-17 which has just a main cargo compartment. As a result, the onload/offload times of the C-X would be one hour longer than the C-17's due to a more complex cargo compartment. Also, maintenance availability was assumed similar for both aircraft. Since only the capability of each aircraft was analyzed it was assumed the C-17 and C-X would not be crew limited – DNIF, leave, etc. would not negatively impact flight operations for this evaluation.

Route Structure

To compare the C-X to the C-17, three different length routes were used to evaluate each aircraft: short, medium and long routes were used. All the routes started from Charleston AFB in South Carolina. The short route offloaded at Ramstein AB, Germany then returned to Charleston. The medium route offloaded at Doha International, Qatar and the long route offloaded at Diego Garcia, in the Indian Ocean. Al Udied AB was the preferred offload location instead of Doha for the medium route but it did not exist in the database and the airfields are only 10 miles apart. Fuel stops on missions varied based on aircraft range. For example, the medium route required a fuel stop in Ramstein for the C-17 before the offload in Doha but not the C-X.

Both aircraft were to fuel at Ramstein on the return flight. Even though both aircraft are air refuelable, all calculations were conducted without this capability.

In determining the routes chosen, the range equation for the C-X was modified properly to illustrate its 6800 range with its design load of 40 tons. The equations were set up in the program for a C-17 which has a much shorter design range of 2940 Nm.

Comparative Fleet size

The C-17 was the primary competitor in determining the capabilities and feasibility of the BWB EET. For many reasons the BWB EET would initially supplement the current fleet of C-17s and C-5s then possibly replace the whole C-17 fleet once it is retired. A direct comparison with the C-5 Galaxy was not used because the C-5 is primarily used for oversized and outsized cargo. Fleet sizes for both aircraft were varied in size and combinations of the two aircraft were used against pure solutions of each aircraft. A fleet of 20, 50, and 100 aircraft were used for each aircraft over each different route length. Also, a combination of equal numbers of C-17s and C-Xs were evaluated over the different routes.

Assumptions for AMPCALC

AMPCALC can apply many factors in evaluating an aircraft for a given mission. For the purpose of this research crew availability, including crew duty day limitations and Maximum on Ground (MOG) aircraft were not set as constraining requirements to evaluate the BWB EET. The focus was on the capability of the new aircraft and not on crew limits. Crew ratios for both the C-17 and BWB EET would most likely be the same based on the new aircraft having an identical crew configuration.

MOG is actually more of an important factor because the aircraft's footprint determines the infrastructure that is needed to support it. Real world MOG is usually based on working MOG which is a combination of physical parking slots, fuel availability and support crews required to work so many aircraft. Even though this is an important factor for determining the capability of the BWB EET, it was not set as a limiting factor. This was to limit the amount of variables and complexity of model. It is important to note, that even with a wider wingspan the BWB EET is significantly shorter than a C-17 and if Boeing incorporates folding wing tips then the BWB EET will fit well inside a C-17's ramp footprint.

Hypothesis

Based on the data that already exist for the X48B, the new BWB EET should be a more capable aircraft compared to the C-17, but it does have some limitations that the C-17 does not. First, since a BWB-designed aircraft is much more fuel efficient based on its structure, it should be able to fly longer and require less enroute stops. This cuts down on ground times which the C-17 would still require. The cruise speed of the new EET is higher than that of a C-17 making it faster from origin to destination. Both these factors will decrease the need for air refueling and reduce its mission footprint on other weapon systems. Another factor that would affect the capability of the BWB EET is its ability to carry 19 pallets compared to the C-17s 18. AMPCALC only calculates an aircraft's cargo capability by weight, not the number of pallets.

Even though Boeing's design is more efficient, it cannot carry as much weight compared to the C-17. Since AMPCALC does not use pallet positions to determine capability, the weight advantage is clearly for the C-17. In reality, most if not all airlift missions, bulk-out before they weight-out for palletized cargo. This is not always the case for oversized or outsized cargo, for

example carrying an Abrams M1-A2 main battle tank on a C-17 or even a C-5 will weight out before bulking. With each aircraft having advantages and disadvantages, the results should be close with the BWB EET, C-X doing better on the longer missions.

IV. Results and Analysis

After setting up the AMPCALC model for each distance and aircraft setting, the following results were obtained and are shown in Table 6. The closure time using the C-17 and the C-X were very close for each length of mission but in each case the C-X closed first. A blend of C-Xs and C-17s produced a closure time between either non-blended mix, for each route distance. On the surface, it appears the capabilities of the two aircraft are nearly identical. Closer examination shows the strengths of each aircraft were offset by a relative weakness. The C-17's shorter maximum range was mitigated by its larger cargo capacity. The C-X's time savings attained via its higher mach speed and longer range capability was neutralized by its lower design cargo capability.

Closure Days

For all initial runs, using 8230 bulk tons cargo, the C-X was slightly quicker in closure time whether it was based on 20, 50 or 100 aircraft. Looking at the combination of both aircraft, closure time equaled the longest closure rate, which was the C-17. This phenomenon took place because how AMPCALC divides the workload between aircraft. It evenly splits the load with excess tonnage going to the C-X. It then treats aircraft separately and whichever one has the longest closure rate it determines that one to be the limiting factor, which normally is the C-17. For example, looking at the medium route to Al Udied AB, the closure day for the combination of 100 aircraft was 5.22, the same for the C-17 but the individual number for each aircraft was 5.22 (C-17) and 5.17 (C-X). For the C-X with 100 aircraft the closure day was 4.92 and 5.22 for the C-17. All test runs are shown in Table 6.

			Bulk Cargo 8,230 Tons							
Route Length	**Short**									
Destination	**Ramstein AB, Germany**									
	C-17	**BWB EET**	**Combo**	**C-17**	**BWB EET**	**Combo**	**C-17**	**BWB EET**	**Combo**	
# of Aircraft	20	20	10 + 10	50	50	25 + 25	100	100	50 + 50	
Closure	13.19	13.05	13.19	5.66	5.58	5.66	3.15	3.09	3.15	days
Cargo per day	624	631	626	1454	1475	1462	2612	2666	2634	tons
Mission per day	13.88	15.78	14.91	32.34	36.93	34.82	58.09	66.74	62.76	msns
Break Even Point	57	56	5.04	Closure days						
Cargo Split			311/315			724/737			1301/1333	
Route Length	**Medium**									
Destination	**Al Udied AB, Qatar**									
	C-17	**BWB EET**	**Combo**	**C-17**	**BWB EET**	**Combo**	**C-17**	**BWB EET**	**Combo**	
# of Aircraft	20	20	10 + 10	50	50	25 + 25	100	100	50 + 50	
Closure	21.76	21.35	21.76	9.35	9.03	9.35	5.22	4.92	5.22	days
Cargo per day	378	385	379	888	911	882	1577	1671	1584	tons
Mission per day	8.41	9.65	9.03	19.57	22.81	21.02	35.07	41.83	37.73	msns
Break Even Point	35	34	12.9	Closure days						
Cargo Split			188/191			438/444			785/798	
Route Length	**Long**									
Destination	**Diago Garcia, Indian Ocean**									
	C-17	**BWB EET**	**Combo**	**C-17**	**BWB EET**	**Combo**	**C-17**	**BWB EET**	**Combo**	
# of Aircraft	20	20	10 + 10	50	50	25 + 25	100	100	50 + 50	
Closure	29.58	29.23	29.58	12.68	12.44	12.68	7.04	6.85	7.04	days
Cargo per day	278	282	279	649	661	651	1168	1202	1174	tons
Mission per day	6.19	7.05	6.64	14.43	16.55	15.51	25.98	30.08	27.98	msns
Break Even Point	49	48	12.91	Closure days						
Cargo Split			139/140			323/328			582/593	

Table 6. Results of 8,320 Ton Test

A break even point for the number of aircraft was also determined for each route length and is shown in Table 6 above. Since there was not a large difference in closure time between the C-X and C-17, it was not surprising to see the breakeven numbers so close. For the short mission to Ramstein AB, 56 C-Xs were needed compared to the 57 C-17s to close in 5.04 days. For the medium route to Al Udied AB, 34 C-Xs were required compared to the 35 C-17s to close in 12.9 days. Finally, for the long route to Anderson AFB, 48 C-Xs were required compared to the 49 C-17s to close in 12.91 days.

Cargo Per Day

Even though both aircraft have a planning cargo weight that is 5 tons different, the cargo per day carried was very similar with the C-X being able to carry more. This result occured for a couple of reasons. First, even though the C-17 has a larger cargo capacity it cannot utilize it as much over longer distances. The C-X can carry its full design load for 6800 miles compared to 2940 miles for the C-17. Not only can the C-X carry its load farther it also did it at a higher Mach number, 0.85. For AMPCALC a more conservative number of 0.84 was used to match the Boeing 747F, for which block speeds were already calculated for the model. The block speed was 465 knots for the C-X compared to 410 knots for the C-17. With a higher block speed, and the ability to fly farther without refueling, the C-X did not have as many enroute stops. This means missions per day. By completing more missions per day, the C-X was able to overcome its lower cargo carrying capability and have a higher overall capability than the C-17, as illustrated in all tests runs shown in Table 6.

An important real world factor that AMPCALC fails to analyze is how AF mobility aircraft are loaded. The model uses only the weight capability of each aircraft, whether it is design weight or max allowed weight. It does not use number of pallet positions or volume. This is important because bulk cargo almost never weights out an aircraft; it is always the number of pallets. Various studies and research are currently being conducted to better utilize pallets because they are not carrying enough weight to maximize the capability of the different mobility aircraft. Typically, the only time aircraft weigh out is when they are carrying outsized or oversize cargo, like large equipment (MRAPs or M1A2 Abrams main battle tanks). If AMPCALC considered pallet positions, the result would be a more accurate representation of

real world loading aircraft. It would also better depict utilization of the BWB EET because it can carry 19 pallets with only one pallet height restricted, compared to the C-17s 18 pallet positions.

Missions per Day

Since the missions per day are based on many of same factors as cargo per day it was not a surprise to see a similar trend with the C-X compared to the C-17. In every example the C-X could complete more missions, but there was a larger difference for the long route to Diego Garcia. This was due to the C-17 having to make more enroute stops than the C-X. Since all runs were done without air refueling for both aircraft the C-17 had to land at Ramstein AB on each leg going to and from the offload location. The C-X was able to complete 66.74 missions a day with 100 aircraft compared to 58.09 for 100 C-17s.

Another factor for the missions per day was ground times. Even though the C-X had to make less enroute stops, the ground times for onload, offload and expedited were set at one hour more than the C-17 times. This was a conservative approach taken based on possible complexity of the 3 bay cargo configuration and difficulties that might arise from loading or unloading a BWB EET. To see what difference the ground times made a test run was done with ground times set the same for C-X as the C-17. The difference in overall closure time was only 0.04 days which equates to approximately one hour. Further research should be conducted to better evaluate the reduction in grounds times and how it can reduce overall cycle time per mission for the BWB EET.

Follow on Test with 16,460 tons

After the initial trial run with only 8,230 tons of bulk cargo, the cargo was doubled to see if there was a linear affect on the BWB EET performance or if it increased exponentially as the

cargo was increased. Once the model was run there was no large difference in the closure dates between the C-X and C-17. In all cases the C-X closed within one day of the C-17. Tables 7, 8 and 9 illustrate the closure days with the tons per day breakdown for the longest distance, to Diego Garcia for the C-17, C-X and C-17/C-X Combo, respectively.

Aircraft Type	Cargo Closure	Passenger Closure	Tons per Day	Passengers per Day	Ute Limit Reason
	CYCLE 1				
KC-135	0.00	0.00	0	0	NO ACFT
C-5	0.00	0.00	0	0	NO ACFT
C-141	0.00	0.00	0	0	NO ACFT
C-17	29.58	0.00	278	0	UTE
KC-10	0.00	0.00	0	0	NO ACFT
DC-10	0.00	0.00	0	0	NO ACFT
B-747F (Mix)	0.00	0.00	0	0	NO ACFT
MD-11F	0.00	0.00	0	0	NO ACFT
WBP Equiv	0.00	0.00	0	0	NO ACFT
WBC Equiv	0.00	0.00	0	0	NO ACFT
NBC	0.00	0.00	0	0	NO ACFT
C-X	0.00	0.00	0	0	NO ACFT
C-Y	0.00	0.00	0	0	NO ACFT
NEW-3	0.00	0.00	0	0	NO ACFT
NEW-4	0.00	0.00	0	0	NO ACFT
TOTAL	29.58	0.00	278	0	

Input Cycle Change and Optimize Cycle 1

C. Days	==>	48	C-5	15	14
P. Days	==>	42	C-141	0	0
Max closure	==>	29.58	C-17	11	10

Table 7. AMPCALC C-17 Diego Garcia Closure

Cargo Closure	Passenger Closure	Tons per Day	Passengers per Day	Ute Limit Reason
CYCLE 2				
0.00	0.00	0	0	NO ACFT
0.00	0.00	0	0	NO ACFT
0.00	0.00	0	0	NO ACFT
0.00	0.00	0	0	NO ACFT
0.00	0.00	0	0	NO ACFT
0.00	0.00	0	0	NO ACFT
0.00	0.00	0	0	NO ACFT
0.00	0.00	0	0	NO ACFT
0.00	0.00	0	0	NO ACFT
0.00	0.00	0	0	NO ACFT
0.00	0.00	0	0	NO ACFT
29.23	0.00	282	0	UTE
0.00	0.00	0	0	NO ACFT
0.00	0.00	0	0	NO ACFT
0.00	0.00	0	0	NO ACFT
29.23	0.00	282	0	
		Input Cycle Change and Optimize Cycle 2		
C. Days ==>	44	C-5	15	14
P. Days ==>	39	C-141	0	0
Max closure ==>	29.23	C-17	11	10

Table 8. AMPCALC C-X Diego Garcia Closure

Cargo Closure	Passenger Closure	Tons per Day	Passengers per Day	Ute Limit Reason
CYCLE 3				
0.00	0.00	0	0	NO ACFT
0.00	0.00	0	0	NO ACFT
0.00	0.00	0	0	NO ACFT
29.58	0.00	139	0	UTE
0.00	0.00	0	0	NO ACFT
0.00	0.00	0	0	NO ACFT
0.00	0.00	0	0	NO ACFT
0.00	0.00	0	0	NO ACFT
0.00	0.00	0	0	NO ACFT
0.00	0.00	0	0	NO ACFT
0.00	0.00	0	0	NO ACFT
29.46	0.00	140	0	UTE
0.00	0.00	0	0	NO ACFT
0.00	0.00	0	0	NO ACFT
0.00	0.00	0	0	NO ACFT
29.58	0.00	279	0	
		Input Cycle Change and Optimize Cycle 3		
C. Days ==>	31	C-5	1	5
P. Days ==>	50	C-141	0	0
Max closure ==>	29.58	C-17	1	3

Table 9. AMPCALC C-17/C-X Combo Diego Garcia Closure

V. Discussion

By strictly interpreting the AMPCALC results, senior leaders might have a difficult time allocating R&D resources to an aircraft which delivers roughly the same effects as the C-17. Yet, there are key factors that AMPCALC fails to model or predict. Most critically, the BWB EET aircraft is forecast to use 25 to 30 percent less fuel than a C-17 through current research. AMPCALC produced a total C-17 flight hour requirement to close the long distance mission to Diego Garcia at 9,599 hours. Average fuel burn rate in a C-17 is 19,643 pounds/hour per AFI 10-1403. A gallon of JP-8 weighs 6.8 pound, with an average cost of $3/gallon based on numbers used by the DOD in 2008. (McMichael & Maze, 2008) As fossil fuels become more scale this number will sure rise. The cost for fuel, then to close this mission using exclusively C-17s is $ 83,185,563. If the C-X is used instead, it takes 9,285 hours to close this mission with a fuel burn rate that is at least 25% lower than a C-17. Using that fuel burn the BWB EET would cost only $60,704,343 to close the mission. The government could save $22,481,220 in fuel costs for the mission. Unfortunately, this calculation is beyond the capabilities of AMPCALC but in each scenario the BWB EET had a slightly faster closure rate and with the 25 to 30 percent reduction in fuel burn rate, it will always be a cheaper solution to use the BWB EET. A cost breakdown of all initial tests runs can be found in Appendix B.

AMPCALC provides the user an excellent starting point for planning mobility operations. If the goal of the decision-maker is to receive a rough estimate on time or capability required, early in the planning process, AMPCALC is outstanding tool. The shortcomings of AMPCALC, unfortunately, are its inability to forecast higher fidelity mobility resource estimates, as well as disregarding key factors like fuel cost.

AMPCALC Further Improvements

AMPCALC has an estimated fidelity of approximately 85 percent which is a good start for testing new aircraft for AMC. If more information is gained from Boeing on specific capabilities of the BWB EET then there may be enough data to use AMC's Air Mobility Operational Simulation (AMOS) model. AMOS has a much higher fidelity and is used for real world planning and execution of Timed Phase Force Deployment Data (TPFDD). More accurate information could then be obtained and compared to actual Operational Plans (OPLAN). Also, AMPCALC should be updated so that the user does not need to manipulate any equations used to accurately model an aircraft. Another problem with the AMPCALC is the built in sensitivity analysis is currently not working. This is a useful feature to evaluate and compare different aircraft capabilities or different aircraft mixtures needed to complete a mission deployment.

Next Step for BWB Design and C-X

Once the X-48B and X-48C finish their testing, the next phase of research will be based on the manned BWB demonstrator. If testing keeps producing positive results, then further research can be completed based on actual aircraft data. This would set the stage to analyze more tangible sections of the design. This could include the type and structure of the ramp and door for downloading and uploading. Being able to analyze the loading and unloading of the aircraft could give much more accurate results on load times and subsequent ground times for the BWB aircraft. Another aspect of a full size demonstrator which will play an important part in its capability will be its takeoff and landing length. Based on the complex fly-by-wire system that will be needed to control the aircraft, successful testing will illuminate its true takeoff and landing requirements. The BWB's takeoff and landing distance will determine the necessary

runway length and which airfields the aircraft can access. Future tests can consider the type of surface the BWB could land on; this is important to meeting future Army and AF needs.

A next step for the C-X is more studies on accurate requirements and mission capabilities desired. Once the white papers are produced and studied the next step, a request for proposal (RFP), will be drafted for the defense industry, and aircraft manufacturers can then produce competing models for the AF. Some tradeoffs might have to take place in order to keep costs within ever tighter budgets. Core requirements will remain, but extra capabilities might be diminished to meet cost targets, or fewer aircraft will be procured. No matter what design is chosen for the C-X, a long, time-phased approach will characterize the acquisition of the aircraft. Although, this will help spread the costs of the weapon system over many years, in the end it could cost more.

BWB Implications

What is the future potential of the BWB? There are many applications for BWB but they would most likely start with military applications. Not only could the BWB be used as possible airlifters of many sizes, but there is also interest in using a BWB design for the KC-Y or KC-Z. One of the easier aspects of using a BWB design for air-refueling is fuel can conform to any shape which is very useful in using all space inside a blended wing design. As shown in Figure 20 this is one potential design of a future tanker. A future tanker that is based on a BWB configuration also gives advantages to multiple refueling booms so that multiple aircraft could be simultaneously refueled. Since the BWB EET shows such a lower consumption of fuel, the fuel saved would be used to increase the range and fuel payload of the aircraft. With this, and

multiple booms available for the aircraft, less BWB tankers could be bought, saving the AF acquisition costs.

ERIK SIMONSEN ILLUSTRATION

Future fill up
Shown is a computer-generated illustration of the conceptual Blended Wing Body (BWB) tanker refueling X-45 Unmanned Combat Air Vehicles. Phantom Works is currently studying BWB aircraft concepts.

Figure 21. BWB Tanker (Kim, 2002)

Besides tanker applications, the Air Force is considering an advanced bomber or weapons platform to launch kinetic type munitions. With its large internal bay and increased efficiency, the BWB also shows promises in this area as shown in figure 21. The extended range means, more weapons carried over a longer range. This could help reduce our overseas footprint to decrease infrastructure cost, and reduce risk to our resources overseas. Reduction in overseas basing will help politically since countries will not need to support our military. BWB aircraft could also serve as reconnaissance, surveillance or command and control platforms. No matter what the aircraft's mission, the same advantages of less weight, lower fuel burn and longer range would be realized.

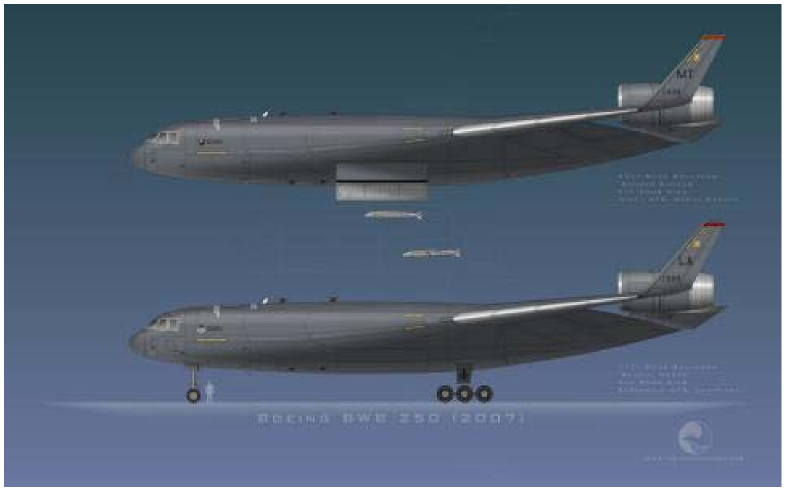


Figure 22. Boeing BWB Bomber (Santiago, 2007)

The last major implication for the advent of BWB aircraft is the civilian airline industry. With almost everything in this industry driven by cost, airlines must find ways to reduce operations costs. Fuel remains one of the largest costs for each airline. By using a BWB aircraft the airlines would be able to reduce their fuel burn, meet current and future noise reduction levels, and increase their passenger loads over longer ranges.   All this would help the airlines to achieve higher efficiency and reduce their dependency on fossil fuels.

Many factors still need to be worked out before a BWB aircraft can be utilized in the civilian sector. Besides design and performance challenges that must be overcome, civilian expectations and perceptions must be changed. This will be a major challenge for marketing to overcome. It will be difficult to convenience people to sit in an aircraft with no direct view of a window or overcome the possible higher g forces associated with sitting much further from aircraft centerline.   Even customers willingness to step on board an aircraft that just looks different from aircraft of the past century, as shown in figure 23, will be difficult. This is a reason why a BWB aircraft might first be utilized in the military to make it a proven and reliable design before it could be utilized in the civilian industry.

Figure 23. Boeing BWB Airliner (Santiago, 2007)

Future Research Possibilities

Further research should include looking at a more variables in the model to include the effect of real world MOGs at each of the offload bases and enroute stops for fuel. Another consideration could be to look at crew availability and limits on crew duty day. Also, a more complex route structure could be evaluated looking at multiple offload bases including the required enroute stops as before. Besides using just bulk, palletized cargo, oversized and outsized cargo could be evaluated. This could be conducted separately or together, including a mixture of passengers based on different load configurations. In the scenario used moving the heavy, light brigades and fighter squadrons, the outsized cargo was 15,241 tons and oversized cargo came to 36,063 tons. Passenger movement included 22,789 soldiers and Airmen. Any future research should include the ability to move the whole compliment of forces to further analyze the capabilities and limitations of a BWB aircraft. Finally, as more details on requirements for the C-X are released they can be incorporated into the research methodology. This also includes more detailed information on X-48 testing and knowledge that will be gained from a full size, manned, BWB demonstrator from Boeing.

This research project focused on the capabilities of a BWB aircraft to help design a future strategic airlifter. Future research should focus more on the cost comparisons between BWB aircraft and legacy airlifters. This may show the true capabilities of the blended wing body, not in terms of how much cargo was hauled, but savings in fuel and money. It could also demonstrate the reduced impact on the environment by significantly reducing carbon emissions and noise pollution.

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Appendix A

			Bulk Cargo 16,460 Tons							
Route Length	Short									
Destination	Ramstein AB, Germany									
	C-17	BWB EET	Combo	C-17	BWB EET	Combo	C-17	BWB EET	Combo	
# of Aircraft	20	20	10 + 10	50	50	25 + 25	100	100	50 + 50	
Closure	25.8	25.57	25.73	10.7	10.59	10.68	5.67	5.59	5.66	days
Cargo per day	638	644	641	1538	1555	1547	2902	2944	2923	tons
Mission per day	14.19	16.11	15.19	34.19	38.92	36.65	64.52	73.7	69.28	msns
Cargo Split			319/322			768/779			1448/1475	
Route Length	Medium									
Destination	Al Udied AB, Qatar									
	C-17	BWB EET	Combo	C-17	BWB EET	Combo	C-17	BWB EET	Combo	
# of Aircraft	20	20	10 + 10	50	50	25 + 25	100	100	50 + 50	
Closure	42.55	41.98	42.43	17.67	17.28	17.62	9.38	9.05	9.35	days
Cargo per day	387	392	388	932	952	936	1756	1819	1765	tons
Mission per day	8.6	9.81	9.2	20.72	23.84	22.18	39.04	45.52	41.82	msns
Cargo Split			193/195			465/471			876/888	
Route Length	Long									
Destination	Diago Garcia, Indian Ocean									
	C-17	BWB EET	Combo	C-17	BWB EET	Combo	C-17	BWB EET	Combo	
# of Aircraft	20	20	10 + 10	50	50	25 + 25	100	100	50 + 50	
Closure	57.91	57.34	57.75	24.01	23.69	23.95	12.71	12.47	12.68	days
Cargo per day	284	287	285	686	695	689	1295	1320	1303	tons
Mission per day	6.32	7.19	6.76	15.24	17.39	16.32	28.8	33.04	30.87	msns
Cargo Split			142/144			342/347			646/656	

Appendix B

Cost Calculations

Givens		
Cost of JP-8	**3**	**$ per gal**
Pounds per gal	**6.8**	
C-17 Fuel Burn	**19643**	**Lbs per hr**
C-X Fuel Burn	**14732**	**Lbs per hr**

Long Mission — **20 Aircraft**

	Hrs per day	Closure	Flight Hrs	Cost	**Savings**
C-17	272.7	29.58	8066.466	69904232	
C-X	272.7	29.23	7971.021	51806948	$18,097,283.94

Long Mission — **50 Aircraft**

	Hrs per day	Closure	Flight Hrs	Cost	**Savings**
C-17	681.75	12.68	8644.59	74914271	
C-X (BWB EET)	681.75	12.44	8480.97	55121316	$19,792,955.00

Long Mission — **100 Aircraft**

	Hrs per day	Closure	Flight Hrs	Cost	**Savings**
C-17	1363.5	7.04	9599.04	83185563	
C-X (BWB EET)	1363.5	6.85	9339.975	60704343	$22,481,219.57

Medium Mission — **20 Aircraft**

	Hrs per day	Closure	Flight Hrs	Cost	**Savings**
C-17	272.7	21.76	5933.952	51423803	
C-X (BWB EET)	272.7	21.35	5822.145	37840518	$13,583,284.85

Medium Mission — **50 Aircraft**

	Hrs per day	Closure	Flight Hrs	Cost	**Savings**
C-17	681.75	9.35	6374.3625	55240413	
C-X (BWB EET)	681.75	9.03	6156.2025	40011695	$15,228,717.95

Medium Mission			100 Aircraft		
	Hrs per day	Closure	Flight Hrs	Cost	**Savings**
C-17	1363.5	5.22	7117.47	61680204	
C-X (BWB EET)	1363.5	4.92	6708.42	43600784	$18,079,420.49

Short Mission			20 Aircraft		
	Hrs per day	Closure	Flight Hrs	Cost	**Savings**
C-17	272.7	21.76	5933.952	51423803	
C-X (BWB EET)	272.7	21.35	5822.145	37840518	$13,583,284.85

Short Mission			50 Aircraft		
	Hrs per day	Closure	Flight Hrs	Cost	**Savings**
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14. ABSTRACT
What is the future design of Air Mobility Command (AMC) aircraft? One possible answer is a blended-wing-body design. The research problem examined in this report is to determine if a future Blended-Wing Body (BWB) aircraft will be more capable as compared to a more conventional design, the C-17. This research shows the capability of the BWB configuration using an AFIT-developed model called AMPCALC and a cost analysis based on those results.
There are two major issues when assessing a BWB aircraft: capability and fuel savings. This research tries to answer if a BWB aircraft, such as being designed by Boeing with NASA and the AF Research Labs, is more capable than a C-17 and what are the potential fuel savings for operating a BWB aircraft over the C-17. This is an early look into the BWB configuration and its merits for consideration as a potential strategic airlifter. The BWB design must now be evaluated to be considered as a future replacement for current AMC airlift aircraft. This research gives decision makers an idea of the possible benefits of this revolutionary concept.

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